BACHELOR THESIS & COLLOQUIUM - ME 141502

CONCEPT FOR A LNG GAS HANDLING SYSTEM FOR A DUAL FUEL ENGINE

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DOUBLE DEGREE PROGRAM
MARINE ENGINEERING DEPARTMENT
FACULTY OF MARINE TECHNOLOGY
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SKRIPSI - ME 141502

KONSEP SISTEM PENANGANAN GAS LNG PADA MESIN *DUAL FUEL*

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PROGRAM DOUBLE DEGREE
DEPARTEMEN TEKNIK SISTEM PERKAPALAN
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SURABAYA 2017

Hochschule Wismar,
University of Applied Sciences Technology, Business and Design
Faculty of Engineering
Department of Maritime Studies

Warnemünde, Dezember 2016

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Student : Leonardo Risman Maruli Sitinjak
Subject : Concept for a LNG gas handling system for a dual fuel engine

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Task

Inside the engine laboratory, at the department of maritime studies in Warnemünde, a diesel engine type MAN 6L23/30A is installed. For future research activities it is intended to change the engine operation mode from diesel to dual fuel. For that it is necessary to develop a concept for the LNG supply system. The supply system concerns the total plant from store tank until the engine manifold.
The following aspects should be particularly considered:

1. Calculation of possible gas consumption at different load points.
2. Selection of necessary components of the gas supply system
3. Design a P&I concept including special requirements for LNG and safety aspects.
4. Installation suggest for the LNG plant in the laboratory building with consideration of legal rules.

The supervising Professor reserves the rights to extend or to narrow down the scope of the task during processing. Establishing contacts with other institutions and companies must be agreed with the supervisors. The publication of the work or parts of it requires the prior permission of the supervisor. The work shall be prepared in accordance with the applicable guidelines of Hochschule Wismar for academic and scientific work. At least two consultations with the supervising Professor are required as part of the processing. The finished work is to be submitted in electronic form and in four printed copies in the organization office in Warnemünde.

Prof. Dr.-Ing. M. Rachow

APPROVAL FORM

CONCEPT FOR A LNG GAS HANDLING SYSTEM FOR A DUAL FUEL ENGINE

BACHELOR THESIS

Submitted to Comply One of The Requirements to Obtain a Bachelor Engineering Degree
in
Double Degree of Marine Engineering (DDME) Program
Department of Marine Engineering - Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember (ITS)
Department of Maritime Studies - Faculty of Engineering
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ROSTOCK
JULY, 2017

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CONCEPT FOR A LNG GAS HANDLING SYSTEM FOR A DUAL FUEL ENGINE

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ABSTRACT

Nowadays, ships are using LNG as main engine fuel because based on the facts that LNG has no sulphur content, and its combustion process, LNG produces low NOx content compared to heavy fuel oil and marine diesel oil. LNG is not only produces low gas emission, but may have economic advantages. In the engine laboratory of maritime studies department in Warnemunde, Germany, there is a diesel engine type MAN 6L23/30 A, where the mode operation of these engine would be changed to dual fuel engine mode operation. Therefore, in this thesis, the use dual fuel engine will be compared where it will utilize natural gas and marine diesel oil and select the required components for fuel gas supply system. By conducting the process calculation, engine MAN 6L23/30 A requires the capacity natural gas of 12.908 m^3 for 5 days at full load. A concept for LNG supply system would be arranged from storage tank until engine manifold. Germanischer Lloyd and Project Guide of dual fuel engine will be used as a guidelines to develop an optimal design and arrangement which comply with the regulation.

KONSEP UNTUK SISTEM PENANGANAN GAS LNG PADA MESIN BERBAHAN BAKAR GANDA

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ABSTRAK

Pada saat sekarang ini, banyak kapal yang sudah menggunakan LNG sebagai bahan bakar utama mesin karena berdasarkan faktanya LNG tidak memiliki kandungan sulphur dan pada saat proses pembakaran LNG menghasilkan kandungan NOx yang rendah dibandingkan dengan heavy fuel oil dan marine diesel oil. LNG tidak hanya menghasilkan gas emisi yang rendah tetapi juga memiliki keuntungan ekonomis. Pada laboratorium mesin, jurusan maritime studies di Warnemunde, Germany, terdapat sebuah mesin type MAN 6L23/30A, dimana mode operasi mesin ini akan dirubah menjadi dual fuel engine. Oleh karena itu, pada thesis ini, penggunaan mesin berbahan bakar ganda akan dibandingkan ketika menggunakan natural gas dan marine diesel oil, kemudian menentukan komponen komponen yang dibutuhkan untuk sistem suplai bahan bakar gas. Dengan melakukan proses perhitungan, mesin MAN 6L23/30 A membutuhkan kapasitas natutal gas sebesar 12.908 m^3 untuk kebutuhan 5 hari pada beban penuh. Sebuah konsep untuk sistem suplai bahan bakar gas akan dirancang dari storage tank sampai engine manifold. Germanischer Lloyd dan Project Guide dual fuel engine akan digunakan sebagai referensi untuk menghasilkan desain yang optimal dan memenuhi standard.

PREFACE

This bachelor submitted to fulfil the requirement to obtain Bachelor of Engineering Degree in Department of Marine Engineering, Sepuluh Nopember Institute of Technology and Hochschule Wismar.

First of all, I would like to thank God for blessing and helping me to complete this bachelor thesis timely. I wish to express my gratitude to my supervisor Prof. Dr.-Ing. Michael Rachow and M.Sc. Steffen Loest for guidance, support, knowledge and advice given for accomplishing this thesis. My thanks to Dipl. Ing. Hartmut Schmidt for the guidance to obtain some data required of engine operation in laboratory. My thanks to Mrs. Rau, Jost, and Ben who helped me during my stay and study in Rostock, Germany.

The greatest honor and appreciation would be finally dedicated to my beloved parents and all my family for the support, love, care and motivation. I would also addressed my appreciation to my beloved family of Marine Engineering students, especially for Double Degree class of 2013, thank you so much for being such a great companion during our togetherness at campus.

Surabaya, July 2017

Leonardo Risman Maruli Sitinjak

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LIST OF ABBREVIATIONS

Abbreviations	Description
LNG	Liquefied Natural Gas
PM	Particulate Matter
HFO	Heavy Fuel Oil
MDO	Marine Diesel Oil
LSHFO	Low Sulphur Heavy Fuel Oil
SFOC	Specific Fuel Oil Consumption
SFGC	Specific Fuel Gas Consumption
FOC	Fuel Oil Consumption
BHP	Engine Power
t	Operating Time
LHV	Lower Heating Value
ρ	Density
IMO	International Maritime Organization
IGC	International Gas Carrier
ISO	International Organization for Standardization
C	Capacity
A	Surface Area
v	Velocity
d	Diameter
Q	Heat Energy
m	Mass of the Substance
C_p	Specific Heat
T	Temperature
GVU	Gas Valve Unit
MAWP	Maximum Allowable Working Pressure
PBU	Pressure Build Up

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CHAPTER I
INTRODUCTION

1.1 Background

Liquefied Natural Gas (LNG) has been used as marine fuel for more than 50 years since the world's first commercial seaborne trade of LNG began in 1964, shipping LNG from Algeria to the U.K [1]. The liquefied natural gas as a marine fuel is regarded as a proven solution for marine applications. The number of ships using LNG as fuel is increasing fast and more and more infrastructure projects are planned or proposed along the main shipping lanes. 63 LNG-fuelled ships (excluding LNG carriers) already operate worldwide, while another 76 new buildings are confirmed (as of May 2015) [2]. Figure 1.1 below shows the number of LNG powered ships in operation and on order by class society.

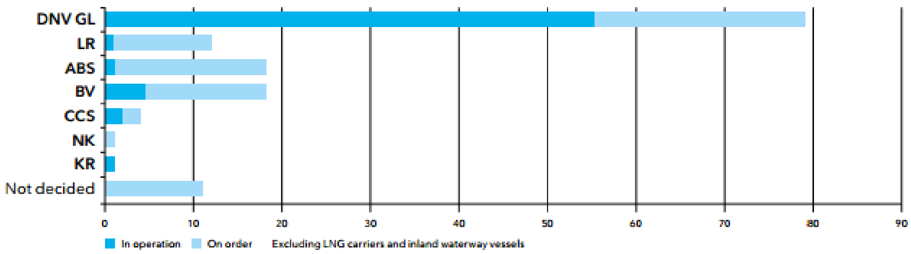


Figure 1.1 Number of LNG Powered Ships in operation and on order
Source: LNG as Ship Fuel (Wuersig 2015)

The main emission product from a diesel engine are CO_2, NO_x, SO_x and particulate matter (PM). These emissions can increasing the temperature on earth, affect the air quality, global warming and other health problems that can impact the environmental. The use of LNG as marine fuel is the proven solution and will contribute to a reduction of these emissions. These reductions will have significant environmental benefits such as improved local air quality, reduced acid rain and contribute to limit global warming.

According to DNV GL, when LNG is used as a ship fuel and in the replacement of conventional oil-based fuels (heavy fuel oil, marine gas oil, or distillate fuels) is the significant reduction in local air pollution - ranging from emissions of SO_x and NO_x to carbon dioxide, particulates (PM) and black carbon. The complete removal of SO_x and particle PM emissions and a reduction of NO_x emission of up to 85% by using LNG is a strong argument for the use of LNG, especially in coastal and sensitive ecosystems. In addition, LNG also reduces CO_2 emissions by at least

20%. As a fuelling option, LNG offers multiple advantages to both human health and the environment. Figure 1.2 below shows the gas emissions reduction by using LNG as a ship fuel.

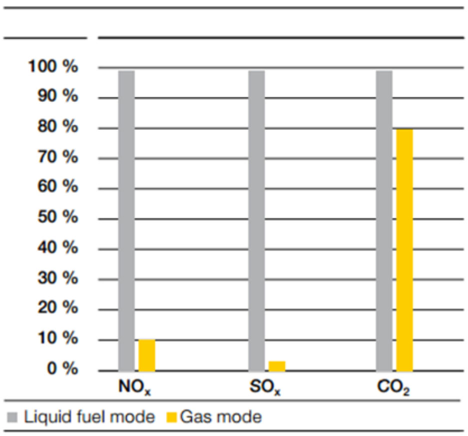


Figure 1.2 Gas Emissions Reduction by Using LNG as a Ship Fuel
Source: MAN Diesel & Turbo "Dual Fuel Upgrade"

One of the main reason that makes LNG become the preferable fuel is the lower price compared to Heavy Fuel Oil (HFO), Marine Diesel Oil (MDO) and Low Sulphur Heavy Fuel Oil (LSHFO). DNV GL was made fuel price scenario for the basic assumption. Starting year for the fuel price scenario is 2010 and 650 \$/t (=15.3 \$/mmBTU) for HFO and 900 \$/t (=21.2 \$/mmBTU) for MGO are set. LNG is set at 13 \$/mmBTU which includes small-scale distribution costs of 4 \$/mmBTU [4]. Figure 1.3 below shows the fuel price scenario of HFO, MDO, LSHFO, and LNG.

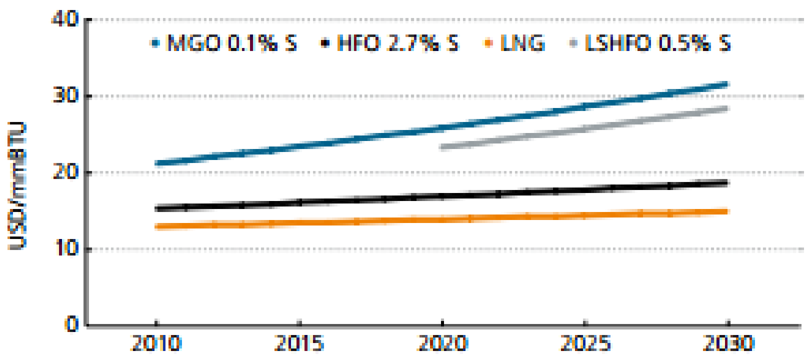


Figure 1.3 Fuel Price Scenario
Source: Costs and Benefits of LNG as Ship Fuel for a Container Vessels (Andersen, Clausen, Sames, 2013

According to the facts above, it is possible to use LNG as marine fuel. At the laboratory of maritime studies department in Warnemünde, a diesel engine type MAN 6L23/30A is installed. For future research activities, it is intended to change the engine operation mode from diesel to dual fuel. It's required an additional components to supply LNG from storage tank to engine manifold, such as LNG tank, water spray pump, LNG pump, vaporizer, and gas valve unit (GVU). In this bachelor thesis, will discuss about the concept design of fuel gas supply system from storage tank until the engine manifold based on legal rules and safety aspects that required by regulation.

1.2 Statement of Problems

Based on the description above, the problem statement that can be concluded in this thesis are:

1. How to determine the fuel oil and fuel gas consumption at different loads? There are several input parameters used on the calculation of fuel oil and fuel gas consumption, such as: specific fuel oil consumption (SFOC), specific fuel gas consumption (SFGC), and operating time. For fuel oil consumption calculation, the SFOC will be obtained from data actual of engine operation. For fuel gas consumption calculation, the SFGC will be obtained from engine project guide that has been converted to dual fuel engine. The operating time of engine operation is 8 hours where this number is required to calculate the capacity of LNG tank.
2. How to determine the required components of gas supply system from storage tank until engine manifold? To determine the required components is based on the project guide of dual fuel engine. In this bachelor thesis, there are three project guide that used as reference to determine the required components, such as MAN 51/60 DF, MAN 35/44 DF, and Wartsila 34 DF. The specification of the components is based on the fuel gas consumption calculation result.
3. How to design the gas supply from storage tank until engine manifold? Germanischer Lloyd and project guide of dual fuel engine are used as guidance to design the fuel gas supply system. In this bachelor thesis, the safety aspects also will be arranged for supporting the process of fuel gas supply, such as safety aspect in LNG tank, pipeline, gas valve unit, and engine room.
4. How to install the LNG plant in the laboratory at department of maritime studies in Warnemünde? All the required components of fuel gas supply system is to be installed that based on the regulation of classification

society. The dimension of the component should be considered because the laboratory of maritime studies department in Warnemünde have limited dimension.

1.3 Research Limitations

The limitation of the problem that discussed on this thesis are:

1. Calculation of fuel oil and fuel gas consumption based on the engine project guide and data actual of engine operation
2. Analysis of this research focus on the diesel engine type MAN 6L23/30A that installed in the engine laboratory at the department of maritime studies in Warnemünde
3. This thesis is focusing on the concept design of fuel gas supply system from storage tank until engine manifold
4. Economic analysis is not including in this thesis

1.4 Research Objectives

The objectives of this thesis are:

1. Determine the possible gas consumption at different loads
2. Determine the necessary components of the gas supply system
3. To design the P&I concept including special requirements for LNG and safety aspects
4. To arrange the LNG plant in the laboratory building with consideration of legal rules

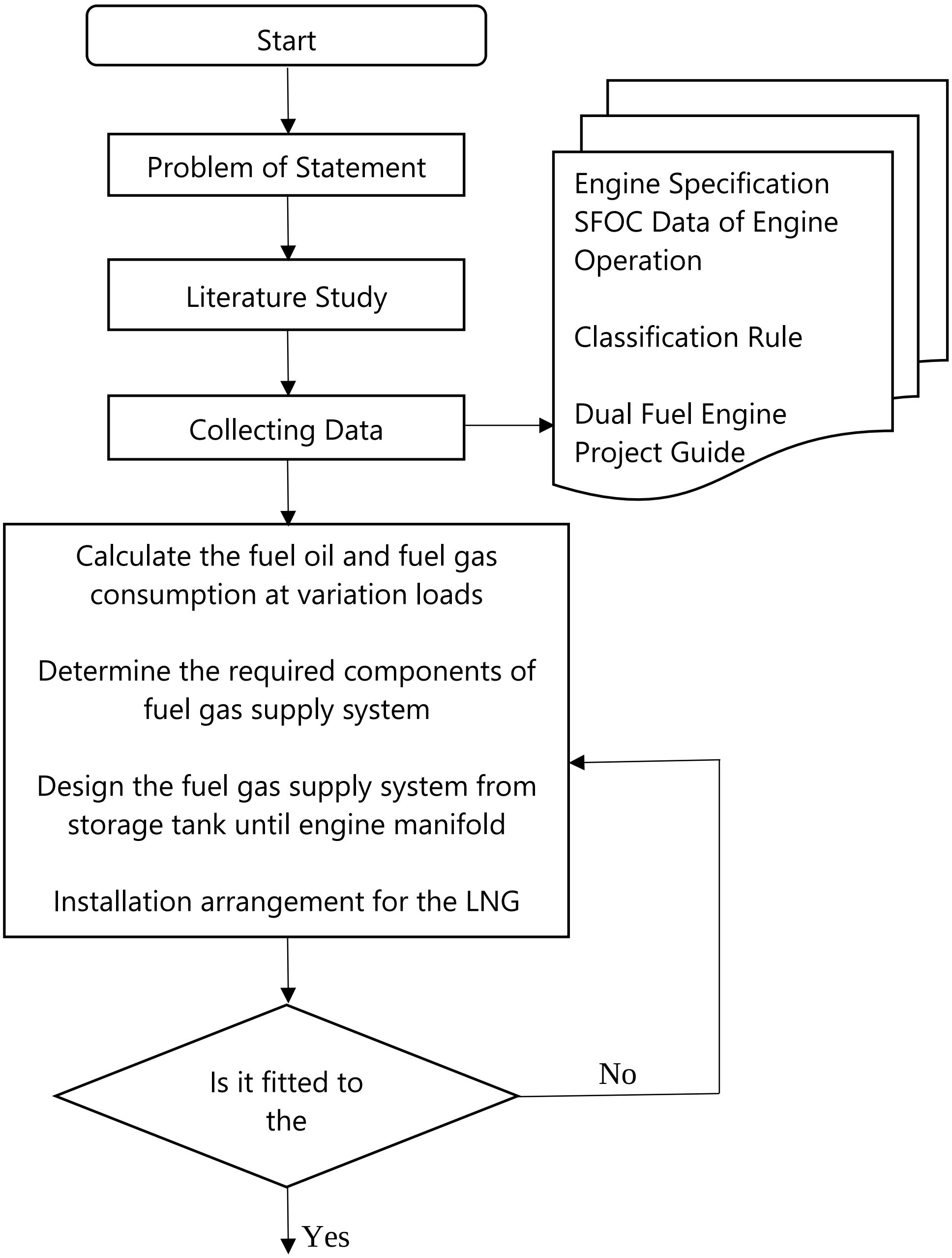
1.5 Research Benefits

The benefits that can be obtained from this bachelor thesis are:

1. Understand the required equipment for fuel gas supply system that based on the calculation result
2. Understand the regulation requirement to design a concept of fuel gas supply system and to arrange the LNG plant in the laboratory building.

CHAPTER II
RESEARCH METHODOLOGY

2.1 Schematic Diagram of Work



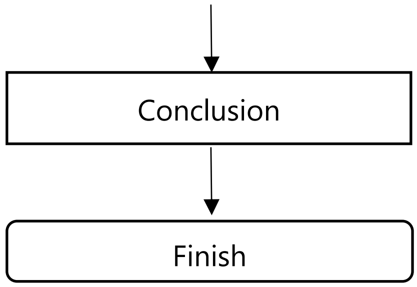


Figure 2.1 Methodology Flow Chart Diagram

2.2 Detail of Work

2.2.1 Problem of Statement

In this thesis, the main problem is changing the engine operation mode from diesel to dual fuel which installed inside the engine laboratory, at the department of maritime studies in Warnemünde. The diesel engine type is MAN 6L23/30A. According to the problem above, it generated problem formulation, such as gas consumption at variation loads, components of the gas supply system, design P & I concept including special requirements and safety aspects.

2.2.2 Literature Study

Literature study is the stage to get all the information to solve the problem obtained. Many information should be obtained, such as basic theory of LNG characteristics, how to calculate the fuel oil and fuel gas consumption, what are the supporting components of fuel gas supply system, what is the consideration to design the concept of fuel gas supply system, how to install the required component into the laboratory building and many others. Most of the information regarding concept design of fuel gas supply system can be obtained from Germanischer Lloyd as classification society and dual fuel engine project guide. Some information are also can be obtained from papers, journals, thesis and researches that able to support this thesis.

2.2.2 Collecting Data

In this stage, data collection is required to develop the concept of fuel gas supply system. The data supported in this thesis are engine specifications, dual fuel engine project guide, and classification regulation of gas supply systems. Engine project guide is required to find out the engine specifications and engine dimensions. In this thesis, the calculation of fuel oil consumption and vaporizer is based on data actual of engine operation. Therefore, the engine will be operated to get the actual data of specific fuel oil consumption (SFOC), engine water cooling temperature and exhaust gas temperature.

2.2.3 Fuel Oil Consumption Calculation

In this stage, fuel oil consumption will be calculated in several variations of load, such as 10%, 25%, 50%, 75%, and 100%. The fuel oil consumption will be calculated based on the data from project guide and data actual of engine operation. Therefore, SFOC from project guide 6L23/30 A MAN is required to calculate the fuel consumption. The data actual of SFOC will be obtained after the engine operated.

2.2.4 Fuel Gas Consumption Calculation

In this stage, fuel gas consumption will be calculated to find out the storage tank capacity to store the fuel for certain time of operation, fuel pump capacity, vaporising system and gas valve unit specification. The value of specific fuel gas consumption (SFGC) is required to calculate the fuel gas consumption. There is no information about SFGC for engine
MAN 6L23/30 A. Therefore, the dual fuel engine project guide is needed as reference to get the value of SFGC, such as MAN 51/60 DF, MAN 35/44 DF and Wartsila 34 DF. These engine was converted from single fuel to dual fuel engine. The value of SFGC from each dual fuel engine project guide will be compared and choose the correct one as reference to calculate the fuel gas consumption of engine MAN 6L23/30 A.

2.2.5 Determine the Required Components of Fuel Gas Supply System

This stage is aims to analyse the components required for gas supply system and the decision of components is based on the classification society and dual fuel engine project guide. Germanischer Lloyd regulation will be used as the classification society. The essential components is required to support the fuel gas supply system, such as LNG tank, water spray pump, LNG pump, vaporizer, and gas valve unit (GVU). All the specification of these components will be obtained based on the fuel gas consumption result. The output of this stage is to determine the required components that meet to the engine requirement, dual fuel engine project guide, and classification societies.

2.2.6 Design the Concept of Fuel Gas Supply System

After every consideration is met the requirement, then the next step is design the fuel gas supply system. In this stage, to design a P&I concept including special requirements for LNG and safety aspects from store tank until engine manifold. Safety aspects will be arranged according to Germanischer Lloyd regulation, component manufacturer requirement, and dual fuel engine project guide.

2.2.7 Installation Suggest for the Plant

After the concept design of fuel gas supply system met to the regulation and project guide of dual fuel engine, then all the components can be installed to the laboratory. In this stage, the placement location of each component will be considered because the laboratory at the department of maritime studies in Warnemünde has limited space. The consideration of installation suggest for the components of fuel gas supply system in the laboratory building should be based on the classification societies.

2.2.8 Conclusion

The conclusion of this thesis is to obtain the optimum concept design of gas supply system and safety aspects from storage tank until engine manifold that based on Germanischer Lloyd regulation and dual fuel engine project guide.

CHAPTER III
FUEL GAS CONSUMPTION CALCULATION AND ANALYSIS

In this chapter, the process of fuel oil consumption and fuel gas consumption calculation will be explained. All the parameters of calculation formula are from data actual of engine operation and data from engine project guide. Engine specifications and engine dimensions are required to calculate the fuel gas consumption.

3.1 Engine Overview

This research use engine type MAN 6l23/30 A as case study. The engine is installed inside the engine laboratory, at the department of maritime studies in Warnemünde. This engine had a power of 960 kW and use marine diesel oil (MDO) as the main fuel. This engine is equipped with water brake system. A water brake system is a type of fluid coupling used to absorb mechanical energy and usually consists of a turbine or propeller mounted in an enclosure filled with water. The water brake is utilized to measure the power output of the engine. The basic operation of a water brake uses the principle of viscous coupling. The output shaft of the engine is coupled to a fan that spins inside a concentric housing. While the engine is running, the housing is filled with a controlled amount of water. The more water that is allowed into the housing, the more load the engine will feel. According to the figure 3.1 below, the water brake in the engine laboratory, at the department of maritime studies in Warnemünde is indicated with a green colour.

Figure 3.1 Engine Type MAN 6L23/30 A and Water Brake Type Zöllner 9N38/12F
Source: Engine Laboratory at the department of maritime studies in Warnemünde

The manufacturer of the water brake is Zöllner type 9N38/12F. It has maximum power of 1200 kW and maximum speed of 3500 r/min. The required of water capacity of this water brake is 25.2 m^3/h. The water temperature of water brake system should be maintained around 40 ℃. The detail specification of engine MAN 6L23/30 A can be seen in the table 3.1 below.

Table 3.1 Engine Specifications and Engine Dimensions

Engine Specifications	
Engine	MAN B&W
Type	6L23/30A
Cylinder Head	6
Engine Power	960 kW
Engine Speed	900 RPM
Engine Built Year	2000
Fuel specification	MDO
Engine Dimensions	
Length	3737 mm
Width	1660 mm
Height	2467 mm
Bore	225 mm
Stroke	300 mm
Dry mass	11 ton

3.2 Fuel Oil Consumption Analysis

Fuel oil consumption calculation is required to find out the fuel gas tank volume. There are 4 parameters to calculate the fuel oil consumption, as it can be seen in formula 3.1 below. Main engine is not working in 24 hours per day. It is only working in 8 hours per day and the volume of fuel gas tank will be calculated for demand 5 days. Before calculate the fuel gas consumption, it's necessary to calculate the fuel oil consumption. In this study, fuel oil consumption will be calculated at variation loads by using formula 3.1 below

$$\mathbf{FOC_{load} = BHP_{load} \times SFOC_{load} \times t \times 10^{-6}} \qquad \textbf{(3.1)}$$

Where,

FOC = Fuel Oil Consumption (ton)

BHP_{load} = Engine Power (kW)

$SFOC_{load}$ = Specific Fuel Oil Consumption (g/kWh)
t = Operating Time
The first step how to calculate fuel oil consumption in different loads is find out the engine power in different loads, as formula 3.2 below

$$\mathbf{BHP_{load}} = \mathbf{BHP_{100\%\ load}} \times \mathbf{Load}\ (\%) \qquad \mathbf{(3.2)}$$

By using formula 3.2 above, engine power in variation loads can be seen as table 3.2 below. These value will be used for fuel oil consumption calculation. Table below shows the result of data retrieval of engine operation in laboratory. In this thesis, fuel oil consumption will be calculated based on project guide and data actual from engine operation.

Table 3.2 Result of Data Retrieval

Load	**12%**	**25%**	**50%**	**75%**	**100%**
Power (kW)	115	240	480	720	960
RPM	490	570	714	820	903
SFOC (g/kWh)	246.96	228.33	218.13	207.78	209.06
Fuel Oil					
Pressure Before Filter (bar)	2.7	2.6	3.5	3.3	3.9
Pressure After Filter (bar)	2.7	2.4	3.1	2.9	3.4
Temperature (°C)	37	36.7	37.2	37.2	36.9
Fuel Oil Cons. (kg/h)	28.4	54.8	104.7	149.6	200.7
Exhaust Gas					
Temp. Cylinder 1 (°C)	241	313.3	333.5	318	349.5
Temp. Cylinder 2 (°C)	233.1	305	327.2	321	353.5
Temp. Cylinder 3 (°C)	230.4	301	328.5	322.8	347.2
Temp. Cylinder 4 (°C)	222.9	301.6	323.4	311.7	341.3
Temp. Cylinder 5 (°C)	223.2	302.3	320.4	313.5	344
Temp. Cylinder 6 (°C)	217.7	285.5	304.2	297.8	322.6
High Temperature Cooling Water					
Temp. Before Cooler (°C)	76.8	77.6	77.8	78.3	79.6
Temp. After Cooler (°C)	73.7	73.2	72.9	73.7	74.7
Flowrate (m^3/h)	21.3	25.1	31.8	36.6	40.4
Low Temperature Cooling Water					
Temp. Before Cooler (°C)	20.5	19.7	22.8	28.9	36.9
Temp. After Cooler (°C)	22.7	22.1	27	34	43.3

Flowrate (m^3/h)	11.7	13.9	17.9	21	21.7

In this thesis, there is a differences between value of Specific Fuel Oil Consumption (SFOC) that attached in project guide MAN 6L23/30A and data actual from engine operation. In data retrieval, engine will be operated in variation loads as table 3.3 below

Table 3.3 Specific Fuel Oil Consumption

Loads (%)	**Power (kW)**	**RPM**	**SFOC from Project Guide (g/kWh)**	**SFOC from Data Actual (g/kWh)**
12	115	490	229	246.96
25	240	570	217	228.33
50	480	714	197	218.13
75	720	820	193	207.78
100	960	903	194	209.06

By using formula 3.1 and table 3.3 above, the result calculation of fuel oil consumption can be seen in table 3.4 below

Table 3.4 Result of Fuel Oil Consumption Calculation

Loads (%)	**Fuel Oil Consumption**	
	Based on Project Guide (ton)	**Based on Data Actual (ton)**
12	0.18	0.19
25	0.42	0.44
50	0.76	0.84
75	1.11	1.20
100	1.49	1.60

From the graph above, it can be known that the result of fuel oil consumption calculation which based on data actual is higher than fuel oil consumption based on project guide. The increase of fuel oil consumption is range from 4.5% - 9.5%. This is because the differences of specific fuel oil consumption between data actual and project guide.

3.3 LNG Consumption Analysis

The calculation of LNG consumption is required to determine the capacity of storage tank. This calculation is using formula as shown in formula 3.1. When the diesel engine is converted to dual fuel engine, the engine power will decrease due to the differences of lower heating value (LHV) between fuel oil and LNG. LHV is the amount of heat released when a specified amount of fuel (usually a unit of mass) at room temperature is completely burned. The value of LHV of MDO and LNG can be seen in table 3.5 below. The power decreasing and the value of specific fuel gas consumption (SFGC) for engine MAN 6L23/30 A will be obtained and analysed based on the dual fuel engine project guide, such as MAN 51/60 DF, MAN 35/44 DF, and Wartsila 34 DF.

Table 3.5 Physical Conversion of LNG and MDO

PHYSICAL CONVERSION		
$\mathrm{LHV_{MDO}}$	42700	kJ/kg
ρ_{MDO}	890	$\mathrm{kg/m^3}$
$\mathrm{LHV_{LNG}}$	49500	$\mathrm{kJ/kg}$
ρ_{LNG}	450	$\mathrm{kg/m^3}$
1 ton LNG	2.2	$\mathrm{m^3}$

Table above is the supporting variable to calculate the fuel gas consumption. The MDO variable is based project guide MAN type 6L23/30A and the LNG variable is based Germanischer Lloyd rules. The Lower Heating Value of LNG is based on the gas composition. A typical composition in volume % is methane (94%), ethane (4.7%), Propane (0.8%), butane (0.2%), and nitrogen (0.3%). [5]

3.3.1 Power Reduction of Engine MAN 6L23/30 A

In this thesis, the amount of power reduction of MAN 23/30 A is referenced by the engine which has been converted to dual-fuel engines. Engine that will serve as the reference for calculating the power reduction is MAN 48/60 B converted to MAN 51/60 DF, MAN 32/44 CR converted to 35/44 DF, and Wartsila 32 converted to Wartsila 34 DF (see table 3.6 below). To find out the amount of power reduction of MAN 6L23/30 A, it should be calculate the power per cylinder volume. Therefore, power per cylinder volume of each engine can be seen in the figure 3.2 below.

Table 3.6 Engine specifications of MAN 48/60 B, MAN 51/60 DF, MAN 32/44 CR, MAN 35/44 DF, Wartsila 32 and Wartsila 34 DF

No	Parameter	Engine Type					
		MAN 48/60 B	MAN 51/60 DF	MAN 32/44 CR	MAN 35/44 DF	Wartsila 32	Wartsila 34 DF
1	Power (kW)	6900	6300	3600	3060	3480	3000
2	RPM	500	500	720	720	750	750
3	Cylinder	6	6	6	6	6	6
4	Bore (mm)	480	510	320	350	320	340
5	Stroke (mm)	600	600	440	440	400	400
6	Cylinder Volume (l)	108.6	122.5	35.4	42.3	32.2	36.3

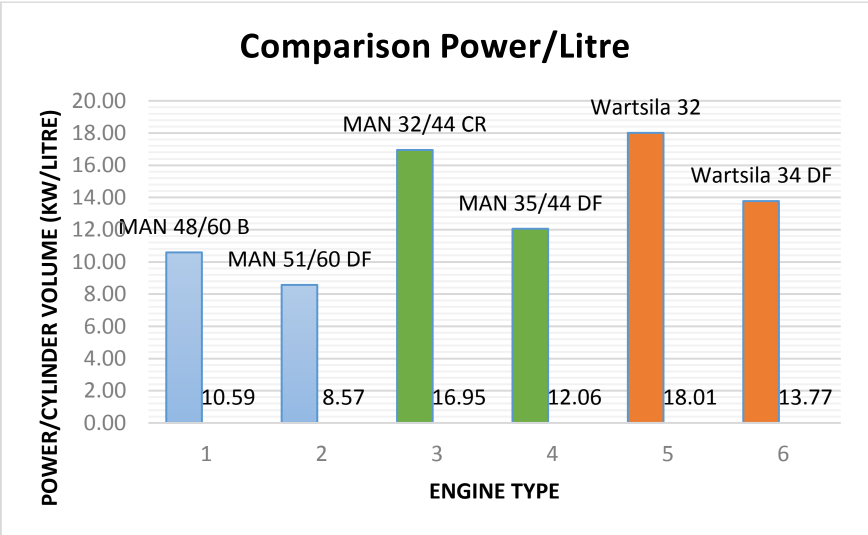


Figure 3.2 Result of Power per Cylinder Volume Calculation

Based on the results from figure 3.2 above, thus the magnitude of power reduction per cylinder/swept volume of each engine can be seen in the table 3.7 below.

Table 3.7 Power Reduction of Engine Converted to Dual Fuel Engine

No	Engine Converted	Power Reduction
1	MAN 48/60 B to MAN 51/60 DF	19.056%
2	MAN 32/44 CR to MAN 35/44 DF	28.87%
3	Wartsila 32 to Wartsila 34 DF	23.53%

To determine the value of power per cylinder volume of engine MAN 6L23/30 A, it should be consider the result of power per cylinder analysis of engine MAN 51/60 DF, MAN 35/44 DF and Wartsila 34 DF. According to figure 3.2 above, the power per cylinder reduction between MAN 35/44 DF and Wartsila 34 DF doesn't have differences significantly. Comparison power per cylinder of MAN 35/44 DF and MAN 51/60 DF have differences significantly. MAN 35/44 DF have less power, less swept volume, and have a higher RPM compared to MAN 51/60 DF. According to the table 3.7 above, the power per cylinder reduction of MAN 35/44 DF is higher compared to MAN 51/60 DF, it's means when the power is decrease, the cylinder volume is decrease but the RPM is increase, then the reduction of power per cylinder will increase. Therefore, the power per cylinder reduction of MAN 35/44 DF will be used to calculate the power reduction of engine MAN 51/60 DF. Before calculate the power reduction, it require to calculate the power per cylinder volume of engine MAN 6L23/30 A. The data required to calculate the power per cylinder volume are

Power : 960 kW
Cylinder : 6
Bore : 225 mm
Stroke : 300 mm

Based on the data above, the power per cylinder volume can be obtained as calculation below

Swept Volume $= \mathrm{Bore}^2 \times 0.7854 \times \mathrm{Stroke}$
$= 0.225^2 \times 0.7854 \times 0.3$
$= 0.01193\ \mathrm{m}^3$
$= 11.93$ litre

Power per Cylinder $= {}^{\mathrm{Power}}/_{\mathrm{number\ of\ cylinders}}$
$= {}^{960\ \mathrm{kW}}/_{6}$
$= 160$ kW

Power per Cylinder Volume $= {}^{\mathrm{Power\ per\ Cylinder}}/_{\mathrm{Cylinder\ Volume}}$
$= {}^{160\ \mathrm{kW}}/_{11.93\ \mathrm{litre}}$

$$= 13.41 \ {}^{\text{kW}}/_{\text{litre}}$$

Thus, the power per swept volume in the engine modified to dual fuel engine be

$$\text{Power per Cylinder Volume}_{(\text{dual fuel engine})}$$
$$= \text{Power per Cylinder Volume}_{(\text{diesel engine})} \times (100 - 28.87)\%$$
$$= 13.41 \ {}^{\text{kW}}/_{\text{litre}} \times 71.13\%$$
$$= 9.54 \ {}^{\text{kW}}/_{\text{litre}}$$

According to the project guide of dual fuel engines that already serve as the reference for calculating the power per cylinder, bore dimension is having changes of 30 mm. Therefore, in this thesis, the bore dimensions of the engine being 255 mm. Based on these value, swept volume after engine modified to dual fuel engine will be

$$\begin{aligned} \text{Swept Volume} &= \text{Bore}^2 \times 0.7854 \times \text{Stroke} \\ &= 0.255^2 \times 0.7854 \times 0.3 \\ &= 0.01532 \text{ m}^3 \\ &= 15.32 \text{ litre} \end{aligned}$$

$$\begin{aligned} \text{Engine power} &= \mathit{Power\ per\ Swept\ Volume} \times \mathit{Swept\ Volume} \times \mathit{cylinder\ number} \\ &= 9.54 \ {}^{kW}/_{litre} \times 15.32 \ litre \times 6 \\ &= 877 \text{ kW} \end{aligned}$$

Table 3.8 below shows the engine power in variation loads after the engine modified to dual fuel engine

Table 3.8 Result of Power Reduction of Engine MAN 6L23/30 A at Variation Load

Load (%)	Power (kW)	SFOC (g/kWh)	SFOC (kJ/kWh)
100	877	208.62	8908.074
75	657.75	210.47	8987.069
50	438.50	219.90	9389.73
25	219.25	231.48	9884.196
12	105.24	250.11	10679.697

3.3.2 Specific Fuel Gas Consumption Analysis

The value of SFOC above is based on the data actual of the engine operation. To determine the LNG consumption, it's requires the specific fuel gas consumption data for natural gas. In this thesis, the specific fuel gas consumption data of natural gas for 6L23 MAN/30 is obtained from comparative analysis of specific fuel gas consumption of engines that already converted to dual fuel engines such as MAN 51/60 DF, MAN 35/44 DF, and Wartsila 34 DF. Table 3.9 below shows the results of a comparative analysis of the specific fuel consumption of those engines

Table 3.9 Comparative Analysis of Specific Fuel Gas Consumption

Load (%)	MAN 51/60 DF		MAN 35/44 DF		Wartsila 34 DF	
	Fuel Oil (kJ/kWh)	Fuel Gas (kJ/kWh)	Fuel Oil (kJ/kWh)	Fuel Gas (kJ/kWh)	Fuel Oil (kJ/kWh)	Fuel Gas (kJ/kWh)
100	7643	7470	7665	7190	8113	7470
85	-	-	7558	7200	7984.9	7620
75	8113	7810	7814	7330	7984.9	7850
50	8412	8390	7900	7820	8326.5	8600
25	9309	11230	8540	9000	-	-
10	13237	18420	-	-	-	-

From the table above, it can be known, at load 50% - 100% specific fuel gas consumption is smaller compared to the specific fuel oil consumption. While at load 10% and 25%, specific fuel gas consumption is greater than specific fuel oil consumption. Percentage change of specific fuel consumption of this engines can be seen in the table 3.10 below.

Table 3.10 Percentage Change of Specific Fuel Gas Consumption

Load (%)	Percentage		
	MAN 51/60 DF	MAN 35/44 DF	Wartsila 34 DF
100	-2.26	-6.20	-7.93
85	-	-4.74	-4.57
75	-3.73	-6.15	-1.69
50	-0.26	-1.01	3.28
25	20.64	5.39	-
10	39.16	-	-

Data in table 3.10 above is used as reference to determine the value of specific fuel gas consumption of engine MAN 6L23/30 A. With some of considerations, the average of specific fuel gas consumption (SFGC) of engine MAN 35/44 DF and Wartsila 34 DF will be used to determine the specific fuel gas consumption of engine MAN 6L23/30 A. This engine having speed of 720 RPM and 750 RPM, where this speed is approaching to the speed of engine MAN 6L23/30 A, while the engine speed of MAN 51/60 DF is 500 RPM. Therefore, the result of SFGC of engine MAN 6L23/30 A can be seen in table 3.11 below.

Table 3.11 Result of Total Fuel Gas Consumption Analysis of Engine MAN 6L23/30 A

Load (%)	Average Value (%)	MAN 6L23/30 A	
		Fuel Oil (kJ/kWh)	Fuel Gas (kJ/kWh)
100	-7.065	8908.074	8279
75	-3.92	8987.069	8635
50	2.145	9389.73	9591

The result of specific fuel gas consumption in the table 3.11 above is the total of specific fuel gas consumption (Natural gas consumption + Pilot fuel consumption). Based on MAN B&W project guide, Wartsila project guide and DNV GL, the amount of pilot fuel oil is below 1% of the energy used by the engine. Therefore, the amount of specific fuel consumption of pilot injector and natural gas consumption can be seen in table 3.12 below

Table 3.12 Specific Fuel Consumption of Pilot Injector

Load (%)	MAN 6L23/30 A		
	Total Fuel Gas (kJ/kWh)	Pilot Fuel (kJ/kWh)	Natural Gas (kJ/kWh)
100	8279	82.79	8196.21
75	8635	86.35	8548.65
50	9591	95.91	9495.09

After the specific fuel gas consumption is obtained, the fuel gas consumption at variation loads can be calculated by using formula 3.1 above. Therefore, the result of fuel gas consumption can be seen in table 3.13 below.

Table 3.13 Result of Fuel Gas Consumption Analysis of Engine MAN 6L23/30 A

Load (%)	Power (kW)	Natural Gas (kJ/kWh)	LNG Consumption	
			Kg/day	Ton/day
100	877	8196.21	1161.71	1.16171
75	657.75	8548.65	908.75	0.90875
50	438.50	9495.09	672.90	0.6729

CHAPTER IV
COMPONENT SELECTION OF FUEL GAS SUPPLY SYSTEM

In this chapter will explain how to determine the components of fuel gas supply system, such as LNG storage tank, water spray pump, vaporizer, LNG pump and Gas Valve Unit. All the calculation to determine the requirement of fuel gas supply system can be seen in the explanation below.

4.1 LNG Storage Tank

According to GL rules VI-3-1 Guidelines for the Use of Gas as Fuel for Ships (Germanischer Lloyd, 2010), the LNG storage tank should be an independent tank. Independent tanks are completely self-supporting and do not form part of the hull structure and it don't contribute to the hull strength. There are currently three types of independent tank designed for storing LNG in accordance with IMO standards which is Type A, Type B and Type C.

1. Type 'A' Tanks

This type of tank is a self-supporting prismatic tank which requires conventional internal stiffening. The maximum allowable tank design pressure in the vapour space for this type of system is 0.7 barg.

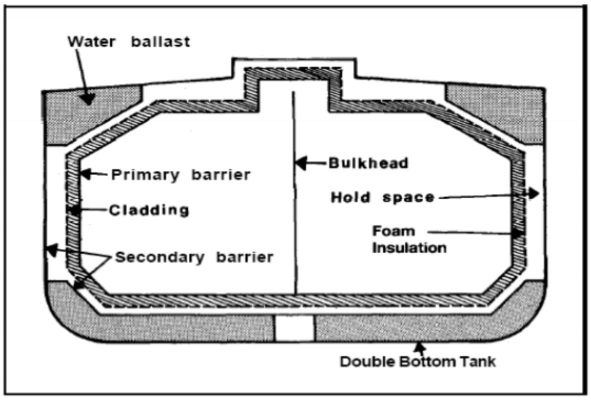


Figure 4.1 Type A Independent Tank
Source: International Safety Guide for Inland Navigation Tank-barges and Terminals (OCIMF, 2010)

The type A tank has a full secondary barrier with the function of providing a redundancy to any possible leakage regardless of the leakage is caused by fatigue cracks or due to over load of the tank causing a rupture of the tank primary barrier

2.2 Type 'B' Tanks

The most common arrangement of Type 'B' tank is a spherical tank. Type 'B' tank requires only a partial secondary barrier in the form of a drip tray. The hold space in this design is normally filled with dry inert gas. The maximum allowable tank design pressure in the vapour is, as for Type 'A' tanks, limited to 0.7 barg.

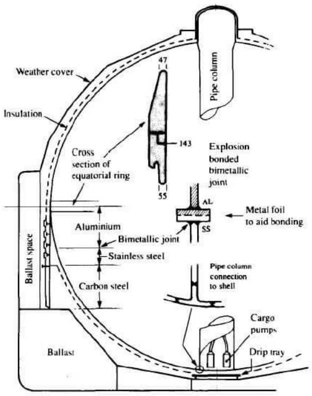


Figure 4.2 Type B Independent Tank

Source: International Safety Guide for Inland Navigation Tank-barges and Terminals (OCIMF, 2010)

Type B tank is not always spherical tank. There is a prismatic type B tank where this tank is improvements of self-supporting tank type A, especially for the construction, supporting structure and isolation system.

2. Type 'C' Tanks

Type 'C' tanks are normally spherical or cylindrical with having design pressures higher than 4 barg. Independent tank type C does not require secondary barrier and the hold space can be filled with either inert gas or dry air.

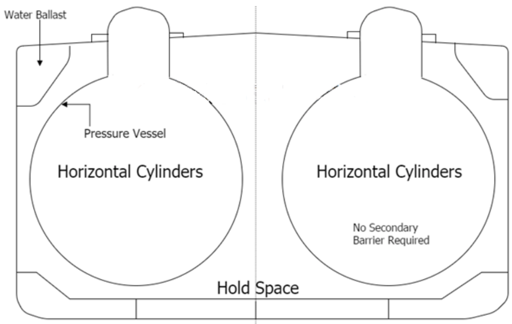


Figure 4.3 Type C Independent Tank

Source: International Safety Guide for Inland Navigation Tank-barges and Terminals (OCIMF, 2010)

According to Wartsila, The standard storage system for transporting various liquid hydrocarbons at low temperatures for several decades has been the IGC (International Gas Carrier) Code Type-C austenitic steel pressure vessels. Therefore, IMO (International Maritime Organization) type C tanks turn out to be the preferred solution for today. Those tanks are very safe and reliable, their high design pressures allow for high loading rates and pressure increase due to boil-off, finally they are easy to fabricate and install. The design pressure of LNG tank type-C range from 4-9 bar. The major disadvantage is the space consumption of this tank type that is restricted to cylindrical, conical and bi-lobe shape. In addition to the unfavourable LNG density these tank shapes lead to a total factor of 3 to 4 times the oil bunker tank volume to carry the same energy in LNG. On top of that, high design pressures reduce the allowable maximum filling limits, if following today's status of regulation. There are three types of LNG storage tank type C, such as:

4.1.1 Double Walled Fuel Storage Tank

- Inner tank: IMO "type C" tank design. Class acceptance of bottom pipe connection
- Outer tank: function of secondary barrier, creating a double containment system
- Capacity range from 30-1000m^3
- Tank design pressure range from 8.5-9 bar
- Layer Insulation (MLI) / Vacuum
- Inner/outer vessels manufactured in austenitic stainless steel or 9% Ni steel
- Tank Saddles & Tank Connection Space directly attached to the outer tank

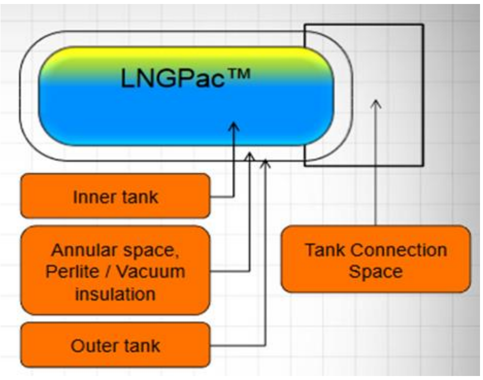


Figure 4.4 Double Walled Fuel Storage Tank
Source: Gas Storage and Supply System (Piero Zoglia, 2013)

4.1.2 Single Walled Fuel Storage Tank

- IMO "type C" tank design. All pipe connections above maximum liquid level
- Capacity range from 600-2500 m^3
- Tank design pressure range from 4-6 bar
- Tank material: austenitic stainless steel or 9% Ni steel
- Polyurethane insulation
- Tank Connection Space separated from Tank
- Dome on top of Tank for all tank pipe connections

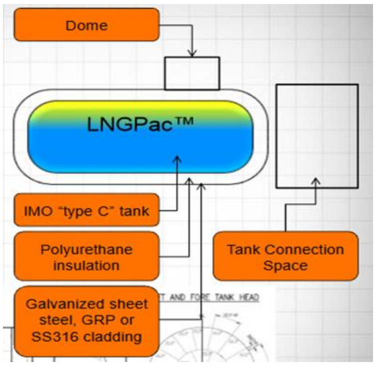


Figure 4.5 Single Walled Fuel Storage Tank
Source: Gas Storage and Supply System (Piero Zoglia, 2013)

4.1.3 ISO (International Organization for Standardization) Marine Type LNG Container

- ISO containerized LNG tank, specifically designed for marine applications
- Every container is docked in a dedicated "docking station", designed for multiple, horizontal and vertical stacked container arrangements
- Each ISO LNG container is equipped with its own process and safety equipment, meeting classification requirements

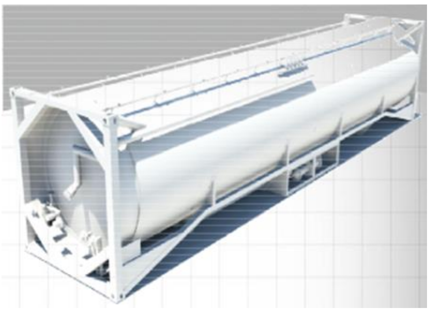


Figure 4.6 LNG Container Tank
Source: A Complete Solution for LNG Fuelled Ships (Barry Yang, 2014)

4.1.4 LNG Tank Selection

Tank selection is based on the calculation of fuel consumption per day, it can be seen in the table 4.1 below. In this thesis, the capacity of LNG tank that will be designed is for endurance of one week (5 days), which means LNG tank should be able to serve the demands of fuel engine for one week (40 hours of engine operation). The type of the tank that will be selected is container tank because it has advantages as described above and also has a tank capacity of small-sized, therefore in this study allows to choose a type of tank container. The demand of fuel engine per week can be seen in table 4.1 below. This calculation is based on data actual of the engine operation.

Table 4.1 Daily and Weekly Fuel Oil and LNG Consumption

LOAD	**DAILY CONSUMPTION**				**WEEKLY CONSUMPTION**			
100 %	MDO		LNG		MDO		LNG	
	m^3	Litre	m^3	Litre	m^3	Litre	m^3	Litre
	1.798	1798	2.5816	2581.6	8.99	8990	12.908	12908

Table 4.1 above shows the demand of fuel oil consumption in one week of 8990 litre, and the demand of LNG consumption in one week of 12908 litre. This result is to be considered for selecting the tank type. According to the description above, LNG tank has 3 types, such as Double Walled Fuel Storage Tank, Single Walled Fuel Storage Tank, and ISO Marine Type LNG Container. Based on the calculation result above, the LNG tank that will be selected is ISO Marine Type LNG Container because container tank having a small size of tank volume compared to single and double walled fuel storage tank. Single walled storage tank has capacity range from 30-1000 m^3 and double walled storage tank has capacity range from 600-2500 m^3. Therefore, it is not possible to install single and double walled storage tank because based on the calculation result, the engine only need 12.908 m^3 in a week. The tank selected can be seen in figure 4.7 below.

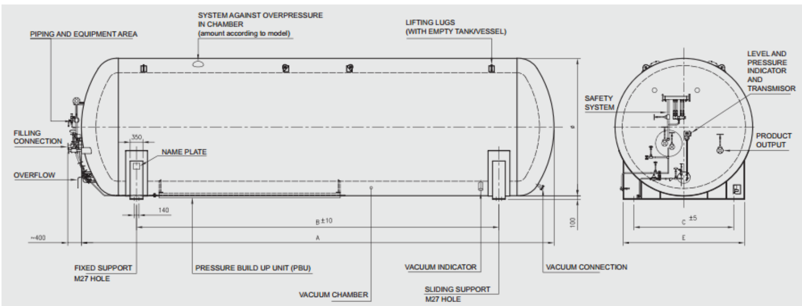


Figure 4.7 Horizontal Cryogenic Tank Type LC16H22-P
Source: Horizontal Cryogenic Tank 2200 H Technical Data

Table 4.2 LNG Tank Specification

Specification	Horizontal Cryogenic Tank
Series	2200 H
Model	LC16H22-P
Design Temperature	-196 ℃
Volume	15.7 m^3
Length	7.595 m
Width	2.2 m
Total Height including vent pipe	2.45 m
Design Pressure	5 Bar
Stored Liquid Weight at 95%	6.9 Ton

The selected tank is horizontal cryogenic tank type LC16H22-P with capacity 15.7 m^3. It mean this type of tank is able to serve the demand of engine operation for a week. According to the calculation result, the demand of LNG for a week is 12.908 m^3. The LNG fuel tank container is fitted with process equipment, namely the valves and instruments required for operational and safety purposes. The LNG fuel tank container is also fitted with a pressure build-up evaporator (PBE) for building up and maintaining an operational pressure of approximately 5 bar in the tank. The detail safety aspects of LNG tank type LC16H22-P will be explained in chapter V.

4.2 Water Spray Pump

Water spray pump should be installed for supplying water to water spray system. This system is for cooling and fire prevention of storage tank. According to GL VI-3-1, Section 3, 3.3.2.2, the system should be designed to cover all areas with an application rate of 10 l/min/m^2 for horizontal projected surfaces and 4 l/min/m^2 for vertical surfaces. In this thesis, the application rate that will be used is 10 l/min/m^2 because the type of the tank is horizontal tank. Therefore, the water spray pump capacity and the diameter pipe of water spray system can be seen in the following calculation.

$$\mathbf{C = 10\ l/min/m^2 \times A_{Tank}} \qquad \textbf{(4.1)}$$

Where

A_{Tank} = Surface Area of LNG tank (m^2)

= 63.31 m^2

C = 10 l/min/m^2 × 63.31 m^2

= 633.1 litre/min

= 37.986 m^3/h

= 0.01056 $\mathrm{m^3/s}$

The following formula can be used for determining the diameter of the pipe.

$$\mathbf{C = A \times v} \qquad \textbf{(4.2)}$$

Where

C = Capacity $\mathrm{m^3/h}$

A = The area of the pipe ($\mathrm{m^2}$)

v = Velocity, 1 m/s *(Assumed)*

So,

A $= {}^{\mathrm{C}}/_{\mathrm{v}}$

$= {}^{0.01056\ \mathrm{m^3/s}}/_{1\ \mathrm{m/s}}$

= 0.01056 $\mathrm{m^2}$

A $= {}^{\pi\ \times\ d^2}/_{4}$

d $= \sqrt{{}^{4A}/_{\pi}}$

$= \sqrt{{}^{4\ \times 0.01056}/_{3.14}}$

= 0.116 m

= 116 mm

After the calculation of pipe diameter is done, it's used to find the specification on DIN catalogue. Therefore, the selected types of galvanised carbon steel pipe based on DIN standard is

Inside diameter : 133.1 mm

Wall thickness : 5.4 mm

Outside diameter : 138.5 mm

Nominal diameter : DN 125

Based on the calculation result above, the specification of water spray pump can be seen in table 4.3 below

Table 4.3 Specification of Water Spray Pump

Manufacturer	**Evergush**	
Type	**XA50/26**	
Flow Rate Capacities		
C	38	$\mathrm{m^3/h}$
Head	19.8	m
Speed	1450	rpm
Required Motor	4	kW

Dimensions		
Length	460	mm
Height	405	mm
Width	320	mm
Weight	101	kg

4.3 Vaporizer

In changing the LNG phase from liquid to gas, vaporizer equipment is required. Vaporizer is a heat exchange medium from liquid to gas where the heat source can be produced from the engine fresh water cooling, exhaust gas, and electric systems. In this thesis, that three systems will be compared. Calculation of capacity of a heat exchanger based on the energy required for changing the LNG phase from liquid to gas, the energy calculation is using the formula 4.3 below

$$\mathbf{Q = m \, . \, C_p \, . \, (T_2 - \, T_1)} \qquad \textbf{(4.3)}$$

Where:

Q = Heat energy (Joules) (Btu),

m = Mass of the substance (kilograms) (pounds),

C_p = Specific heat of the substance (J/kg°C) (Btu/pound/°F),

$T_2 - T_1$ = The change in temperature (°C) (°F)

The first step to calculate the heat energy is determining the value of the mass of the substance or mass of LNG. The demand of LNG in one day is 1161.71 kg. These values can be seen in the calculation of the fuel gas consumption. The fuel gas consumption per hour is required for determining the capacity of heat exchanger, therefore the fuel gas consumption per hour is

m = 1161.71 kg/day

m = $\frac{1161.71 \text{ kg/day}}{8 \text{ h}}$

= 145.214 kg/h

** In one day, the engine only operate in 8 hours.*

The next step is calculate the energy required for LNG phase change from liquid to gas. The initial LNG temperature is -182℃ and the end temperature is 30℃ (this temperature was already in the form of gas). Based on the project guide MAN 51/60DF, temperature natural gas before the engine is 0℃ to 50℃ and in this thesis, the temperature of natural gas before the engine is 30℃. The energy calculation should consider the LNG phase from liquid to gas. Figure 4.8 below shown the LNG phase diagram.

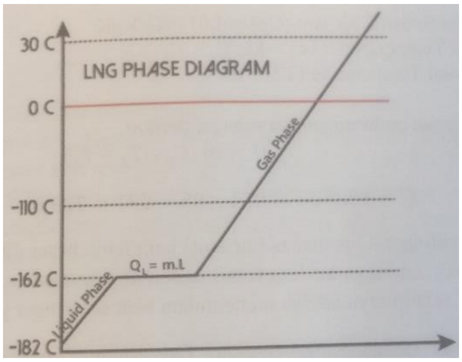


Figure 4.8 LNG Phase Diagram

The following is a calculation of the energy for the LNG phase change from liquid to gas

$Q_1 = 145.214\ \mathrm{kg/h} \times 2.207\ \mathrm{kJ/kg\ K} \times (111.15 - 91.15)\ \mathrm{K}$

$Q_1 = 6409.746\ \mathrm{kJ/h}$

$Q_L = m \times L$

$Q_L = 145.214\ \mathrm{kg/h} \times 0.1294\ \mathrm{kJ/kg}$

$Q_L = 18.79\ \mathrm{kJ/h}$

$Q_2 = 145.214\ \mathrm{kg/h} \times 3.512\ \mathrm{kJ/kg\ K} \times (303.15 - 111.15)\ \mathrm{K}$

$Q_2 = 97918.38\ \mathrm{kJ/h}$

So the total energy needed to change the phase of the LNG from liquid to gas are as follows

$Q_{Total} = Q_1 + Q_L + Q_2$

$Q_{Total} = 6409.746\ \mathrm{kJ/h} + 18.79\ \mathrm{kJ/h} + 97918.38\ \mathrm{kJ/h}$

$Q_{Total} = 104346.916\ \mathrm{kJ/h}$

$Q_{Total} = 28.98\ \mathrm{kW}$

To determine the required capacity of the vaporizer, the natural gas consumption is required. The previous calculation of the fuel gas consumption is still in the LNG form, therefore it is require to change into natural gas form. The liquefaction process reduces the original volume of the natural gas being converted into LNG by a factor more than 600, which allows for its efficient transport and storage [10]. Table 4.4 and 4.5 below shows the requirement of LNG and natural gas consumption at engine operation.

Table 4.4 LNG Consumption

Loads	kg/day	m^3/day	kg/h	m^3/h
100%	1161.71	2.58	145.214	0.323
75%	908.75	2.02	113.60	0.253
50%	672.90	1.50	84.113	0.188

Table 4.5 Natural Gas Consumption

Load	kg/day	m^3/day	kg/h	m^3/h
100%	697026	1548	87128.25	193.50
75%	545250	1212	68156.25	151.50
50%	403740	900	50467.50	112.50

In this thesis, there are 3 systems that will be discussed for the LNG regasification, such as circulating water vaporizer, steam vaporizer, and electric vaporizer. The results of these three systems will be compared to choose the most appropriate system.

The steam vaporizer is uses steam as thermal source. The steam is passing through the outer tube bundles to release heat, and LNG is flowing in the tubes to absorb heat to produce natural gas. The merits of this vaporizer are the compacted construction, higher efficiency, better reliability, temperature controlled easily, and the demerits are the steam source supplied, the higher costs of original invest and operation. This vaporizer often used in LNG carrier ship.

Water circulation vaporizers are self-controlling and do not require any external, expensive flow control devices, temperature monitors or control devices. It is the ultimate, reliable, cost effective, economic solution for simple gas vaporization. The design matches the flow rate of the available water to the required maximum vaporization heat load, ensuring full vaporization of the incoming cryogen with a reasonable gas exit temperature. The water flow rate becomes a fixed parameter simplifying the operating controls. Even if the cryogen flow reduces, full vaporization is achieved and the gas exit temperature approaches closer to the incoming water temperature, but still a value acceptable to the process, since it cannot be higher than the water temperature.

The electric type vaporizers consist of heaters that transfer heat into a medium for conduction into the process tubing. The transfer mediums are normally an aluminium ‘block’ or water filled tank (water bath). The advantage of electric vaporizer are the heater elements are easily removable and replaceable without affecting the integrity of the vaporizer construction. Low pressure drops are attainable along with effective hear transfer rates. The units are lightweight, portable and require a smaller footprint than comparable models. The vaporizer electrical control design comprises a solid state temperature controller, independent auto resetting over temperature switch controller and a separate manual resetting high limit shutdown controller. The disadvantages of electric vaporizer are high power cost to operate and possible limitation in available power.

According to explanation above, circulating water vaporizer will be applied to the fuel gas system because it's more profitable compared to steam vaporizer and electric vaporizer. Circulating water vaporizer has a lower cost operation and only need hot water as a source to vaporize LNG. The hot water can be obtained from engine cooling water system. The temperature of water from engine cooling system can be seen in table 4.6 below.

Table 4.6 Water Temperature of Engine Cooling System

Cylinder	**Temperature (℃)**				
	Load 12%	**Load 25%**	**Load 50%**	**Load 75%**	**Load 100%**
Cylinder 1	74.8	74.7	74.5	75	76
Cylinder 2	75.2	75.3	75	75.7	76.8
Cylinder 3	75.5	75.5	75.3	76	77.2
Cylinder 4	75.2	75.3	75	75.7	76.8
Cylinder 5	74.8	74.7	74.5	75	76
Cylinder 6	91.8	92.5	92.3	93.5	86.9

Based on the water temperature of engine cooling system above, the average of water temperature of load 12% to 100% is 77,8 ℃ until 78,5 ℃. The vaporizer capacity should be able to supply the gas fuel during maximum load. Based on calculation results, the required gas flow rate in 100% load is 145.214 kg/h. The selected vaporizer is shown in table 4.7 below.

Table 4.7 Specification and Dimension of Circulating Water Vaporizer

Vaporizer Type	**Circulating Water Vaporizer**	
Model	**VWB-400**	
Specification		
LNG Flow rate	400	$\mathrm{kg/hr}$
Water Flow rate	5.1	$\mathrm{m^3/hr}$

Dimensions		
Length	0.45	m
Width	0.65	m
Height	2.24	m
Weight	275	kg

According to the specification above, the circulating water vaporizer type VWB-400 can serve the required fuel gas, where the demand of fuel gas in 100% load is 145.214 kg/h. In 100% load of engine operation, the water flow rate of engine water cooling system is 40.4 m^3/hr. This value is based on the data retrieval of engine type 6L23/30 A. It's mean the engine can serve the required water flow rate of circulating water vaporizer type VWB-400 where this type of vaporizer only need 5.1 m^3/hr of water flow rate to vaporize the LNG.

4.4 LNG Pump

LNG pump is required to transfer LNG from storage tank to vaporizer. The LNG pump should be able operate in maximum pressure of LNG and can operate in low temperature, where the temperature of LNG is -182 ℃. The capacity of LNG pump is determined by engine fuel gas requirement. Based on the calculation of LNG consumption, the LNG flow rate at maximum load is 0.323 m^3/h or 5.383 l/min. Therefore, the selected LNG pump should be able operate in 5.383 l/min, it can be seen in table 4.8 below

Table 4.8 Specification and Dimension of LNG Pump

Manufacturer	**Vanzetti**	
Type	**VT-1 32 25**	
Flow Rate Capacities		
$C_{min-max}$	1.4 – 8.1	lpm
Power Installed	3 - 15	kW
Dimensions		
Length	1950	mm
Height	1150	mm
Width	860	mm
Weight	420	kg

4.5 Gas Valve Unit

Before the gas is supplied to the engine, it passes through a Gas Valve Unit (GVU). The main functions of the Gas Valve Unit are to regulate the gas feeding pressure to the engine, and to ensure a fast and reliable shut down of the gas supply. The GVU include a gas pressure control valve and a series of block and bleed valves to ensure reliable and safe operation on gas. The unit includes a manual shut-off valve, inert gas connection, filter, fuel gas pressure control valve, shut-off valves, ventilating valves, pressure transmitters/gauges, a gas temperature transmitter and control cabinets.

Wartsila provides two different types of gas valve unit. One is the gas valve unit open design (GVU-OD, see figure 4.10) which requires installation in an explosion-proof gas valve unit room and airlock is required between GVU room and surrounding space. The other is gas valve unit enclosed design (GVU-ED, see figure 4.9). The gas valve unit enclosed design is a solution where all the equipment is mounted inside a gas tight casing. The GVU with gas tight casing enables the installation of the gas control system directly next to the engine in the engine room (safe area). In this case, the cover acts as the double wall and thus provides for a secure enclosure of the gas control system. This will safely prevent the gas from getting into the safe area in the event of a gas leak in the gas control system. This arrangement allows the GVU-ED to be placed inside the engine room to minimise installation costs. [11]

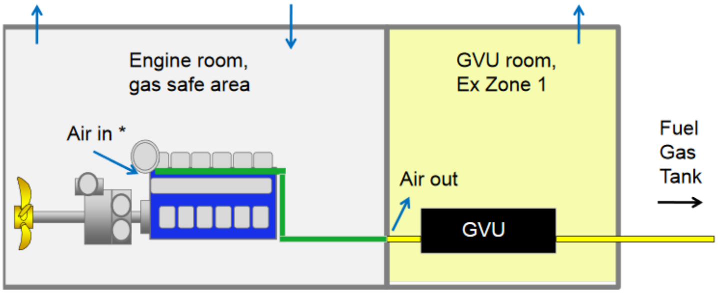


Figure 4.9 Gas Valve Unit Enclosed Design
Source: Dual Fuel Engine Development and Design (Mika Ojutkangas, Wartsila)

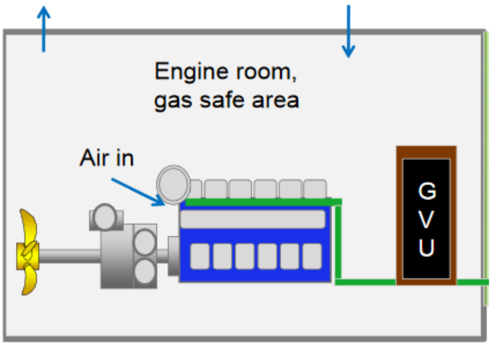


Figure 4.10 Gas Valve Unit Open Design
Source: Dual Fuel Engine Development and Design (Mika Ojutkangas, Wartsila)

Because of some considerations, in this thesis, GVU enclosed design will be installed because the engine room in the laboratory doesn't has enough space to install GVU open design. The selected GVU is referenced from Wartsila 50 DF product guide, where it's provides two kinds of gas valve unit enclosed design, as shown in table 4.9 below.

Table 4.9 Types of Gas Valve Unit Enclosed Design
Source: Wartsila 50 DF Project Guide

Pipe Connection	GVU DN80	GVU DN100
Gas Inlet	DN80 / DN125	DN100 / DN150
Gas Outlet	DN80 / DN125	DN100 / DN150

In this thesis, the selected GVU is GVU DN 100 because the result of pipe diameter calculation of fuel gas system is 151.4 mm or DN150, it showed in table 4.11 below. The dimension of selected GVU can be seen in table 4.10 below.

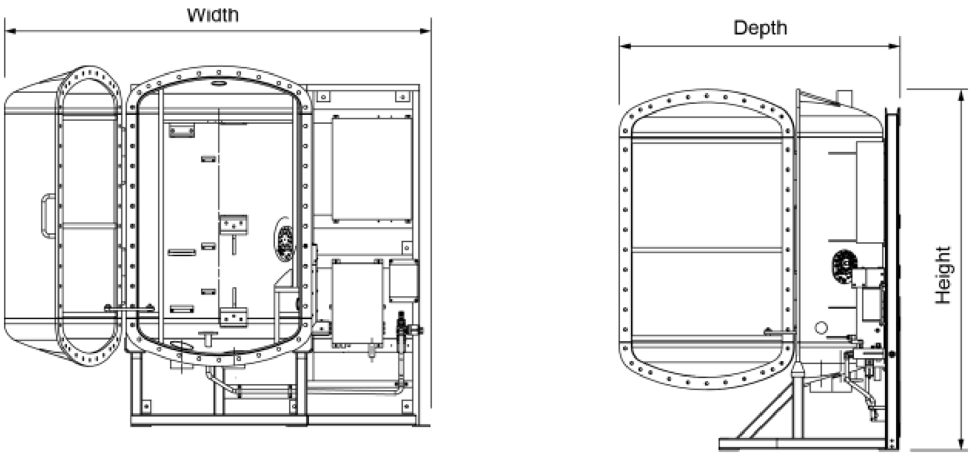


Figure 4.11 Design of GVU-ED
Source: Wartsila 50 DF Project Guide

Table 4.10 Dimension of Gas Valve Unit Enclosed Design
Source: Wartsila 50 DF Project Guide

Manufacturer	Wartsila	
Type	GVU DN100	
Dimensions		
Height	2710	mm
Width	3200	mm
Depth	2200	mm

4.6 Pipe Diameter Calculation

Pipe diameter depends on flow rate and velocity. This pipe diameter calculation is based on the fuel oil consumption per hour of the engine and it's required to select the dimensions of gas valve unit. There is a different pipe diameter between LNG tank to vaporizer and vaporizer to main engine because fuel phase between LNG tank and vaporizer still in liquid phase while the fuel phase between vaporizer and main engine is in gas phase. The calculation of pipe diameter is using formula as

$$\mathbf{C = v \times A} \tag{4.4}$$

Where,

C = LNG and Gas consumption rate ($\mathrm{m^3}/_{\mathrm{s}}$)
= 0.323 $\mathrm{m^3}/_{\mathrm{h}}$, for liquid phase
= 193.50 $\mathrm{m^3}/_{\mathrm{h}}$, for gas phase

v = LNG and Gas velocity ($\mathrm{m}/_{\mathrm{s}}$)

A = Pipe surface area ($\mathrm{m^2}$)

According to Wartsila 50 DF project guide pages 36, the maximum velocity of LNG is 3 $\mathrm{m}/_{\mathrm{s}}$, while the maximum velocity of gas is 20 $\mathrm{m}/_{\mathrm{s}}$. Therefore, in this thesis, the velocity of LNG assumed of 1 $\mathrm{m}/_{\mathrm{s}}$ and for gas velocity assumed of 3 $\mathrm{m}/_{\mathrm{s}}$. The result of pipe diameter can be seen in the table 4.11 below

Table 4.11 Pipe Diameter Calculation Result

No	Phase	Pipe Diameter
1	Liquid Phase	10.7 mm
2	Gas Phase	151.4 mm

After the calculation of pipe diameter is done, it's required to consider the selection of pipe based on the regulation. According to GL rules VI-3-1 section 2.2, the material of gas piping should be accordance with GL rules I-1-6 section 6, where the pipe should be seamless and welded, and should be containing with 9% nickle steel, austenitic steel, and aluminium alloys.

In this thesis, the selected pipe is seamless and welded steel pipe from FW Fernwarme Technik GmbH manufacturer. This pipe is approved by ASTM A 312 material TP316/ TP316L, dimensions according to ASME B 36.19M/B 36.10M or EN 10216-5/ EN10217-7, 1.4401/1.4404, dimensions according to EN ISO 1127 with acceptance test certificate in accordance with DIN EN 10204/3.1.

Based on the pipe diameter calculation result, therefore the selected pipe can be seen as below

Selected pipe for liquid phase

Inside diameter	: 25.4 mm
Insulation thickness	: 20 mm
Annular gap	: 17 mm
Outside diameter	: 101.6 mm

Selected pipe for gas phase

Inside diameter	: 152.4 mm
Insulation thickness	: 50 mm
Annular gap	: 21 mm
Outside diameter	: 304.8 mm

CHAPTER V
DESIGN ARRANGEMENT

5.1 Fuel Gas Supply System

Gas fuel supply system is a system which designed to fulfil engine required when engine operated in variation load. In this thesis, the demand of fuel gas in variation load has been calculated.

Process of gas supply system is started from LNG storage tank where natural gas is in liquid phase. LNG will be transported to vaporizer by using low pressure pump. The capacity of LNG pump is based on gas engine required per hour. Vaporizer type that will installed in this thesis is the result of comparison between circulating water vaporizer, steam vaporizer and electric vaporizer. In the outlet of vaporizer, natural gas have phase changed from liquid into gas phase.

Before gas flowing to engine, previously gas will through gas valve unit (GVU) where GVU will regulate the pressure and temperature of gas. In every connection in the open spaces will use a double pipe flowline.

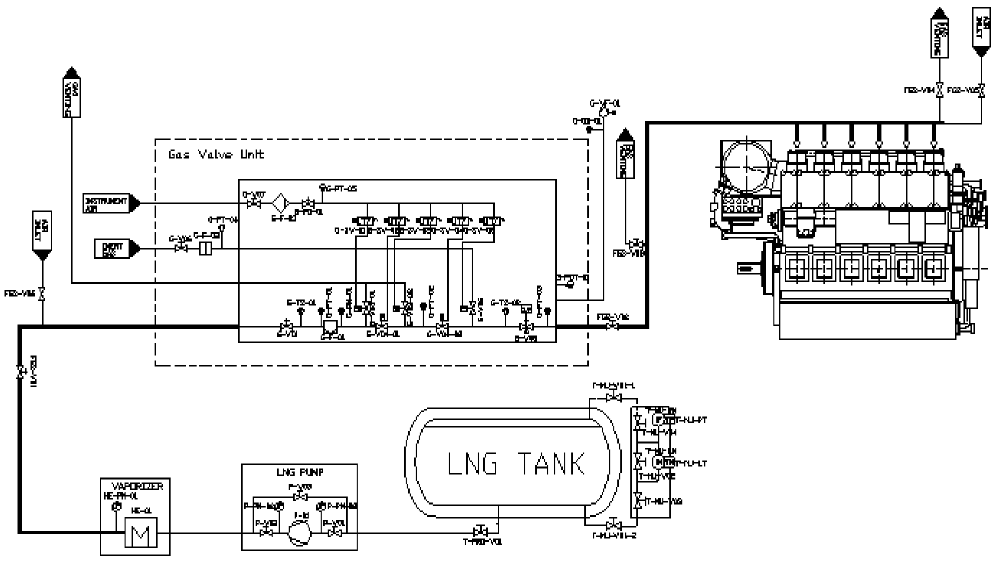


Figure 5.1 Design Arrangement of Fuel Gas Supply System

5.2 Design Requirement

5.2.1 LNG Storage Tank

GL VI-3-1, Section 2, 2.8.1.1
The storage tank used for liquefied gas should be an independent tank designed in accordance with GL Rules, Liquefied Gas Carriers (I-1-6), Section 4.

GL I-1-6, Section 4, 4.2.4
Independent tanks are self-supporting; they do not form part of the ship's hull and are not essential to the hull strength. There are three categories of independent tanks.
Type A independent tanks are tanks which are designed primarily using classical ship-structural analysis procedures. The design vapour pressure P0 is to be less than 0,7 bar.
Type B independent tanks are tanks which are designed using model tests, refined analytical tools and analysis methods to determine stress levels, fatigue life and crack propagation characteristics. The design vapour pressure P0 is to be less than 0,7 bar.
Type C independent tanks (also referred to as pressure vessels) are tanks meeting pressure vessel criteria.

GL VI-3-1, Section 2, 2.8.1.2
Pipe connections to the tank should normally be mounted above the highest liquid level in the tanks. However, connections below the highest liquid level may be accepted after special consideration by the Administration.

GL VI-3-1, Section 2, 2.8.1.3
Pressure relief valves as required in the GL Rules, Liquefied Gas Carriers (I-1-6), Section 8 should be fitted.

GL VI-3-1, Section 2, 2.8.1.3
The outlet from the pressure relief valves should normally be located at least B/3 or 6 m, whichever is greater, above the weather deck and 6 m above the working area and gangways, where B is the greatest moulded breadth of the ship in metres. The outlets should normally be located at least 10 m from the nearest:

1. Air intake, air outlet or opening to accommodation, service and control spaces, or other gas safe spaces; and
2. Exhaust outlet from machinery or from furnace installation.

GL VI-3-1, Section 2, 2.8.1.3
Storage tanks for liquid gas should not be filled to more than 98 % full.

GL VI-3-1, Section 2, 2.8.1.3
Gas in a liquid state may be stored in enclosed spaces, with a maximum acceptable working pressure of 10 bar.

5.2.2 Gas Piping System

GL VI-3-1, Section 2, 2.5.17
Gas piping should not be led through other machinery spaces. Alternatively, double gas piping or a ventilated duct may be approved, provided the danger of mechanical damage is negligible, the gas piping has no discharge sources and the room is equipped with a gas alarm.

GL VI-3-1, Section 2, 2.5.18
An arrangement for purging gas bunkering lines and supply lines (only up to the double block and bleed valves if these are located close to the engine) with nitrogen should be provided.

5.2.3 System Configuration

GL VI-3-1, Section 2, 2.6.2.1
All gas supply piping within machinery space boundaries should be enclosed in a gas tight enclosure, i.e., double wall piping or ventilated ducting.

GL VI-3-1, Section 2, 2.6.2.2
In case of leakage in a gas supply pipe making shutdown of the gas supply necessary, a secondary independent fuel supply should be available.

GL VI-3-1, Section 2, 2.6.2.2
Gas supply piping within machinery spaces may be accepted without a gastight external enclosure on the following conditions

1. Pressure in gas supply lines within machinery spaces should be less than 10 bar, e.g., this concept can only be used for low pressure systems.
2. A gas detection system arranged to automatically shut down the gas supply (also oil fuel supply if dual fuel) and disconnect all non-explosion protected equipment or installations should be fitted.

5.2.4 Gas Supply System in gas machinery spaces

GL VI-3-1, Section 2, 2.7.1.1

Gas supply lines passing through enclosed spaces should be completely enclosed by a double pipe or ventilated duct. This double pipe or ventilated duct should fulfil one of the following:

1. The gas piping should be a double wall piping system with the gas fuel contained in the inner pipe. The space between the concentric pipes should be pressurised with inert gas at a pressure greater than the gas fuel pressure. Suitable alarms should be provided to indicate a loss of inert gas pressure between the pipes. Alternative arrangements like monitored evacuated double wall pipes can be accepted by GL. When the inner pipe contains high pressure gas, the system should be so arranged that the pipe between the master gas valve and the engine is automatically purged with inert gas when the master gas valve is closed
2. The gas fuel piping should be installed within a ventilated pipe or duct. The air space between the gas fuel piping and the wall of the outer pipe or duct should be equipped with mechanical under pressure ventilation having a capacity of at least 30 air changes per hour. This ventilation capacity may be reduced to 10 air changes per hour provided automatic filling of the duct with nitrogen upon detection of gas is arranged for. The fan motors should comply with the required explosion protection in the installation area. The ventilation outlet should be covered by a protection screen and placed in a position where no flammable gas-air mixture may be ignited.

GL VI-3-1, Section 2, 2.7.1.2

The connecting of gas piping and ducting to the gas injection valves should be so as to provide complete coverage by the ducting. The arrangement should facilitate replacement and/or overhaul of injection valves and cylinder covers. The double ducting should be required also for gas pipes on the engine itself, and all the way until gas is injected into the chamber.

5.2.5 Ventilation system

GL VI-3-1, Section 2, 2.10.1.1

Any ducting used for the ventilation of hazardous spaces should be separate from that used for the ventilation of non-hazardous spaces.

GL VI-3-1, Section 2, 2.10.1.3
Any loss of the required ventilating capacity should give an audible and visual alarm at a permanently manned location.

GL VI-3-1, Section 2, 2.10.1.8
The required capacity of the ventilation plant is normally based on the total volume of the room. An increase in required ventilation capacity may be necessary for rooms having a complicated form.

GL VI-3-1, Section 2, 2.10.1.9
Non-hazardous spaces with entry openings to a hazardous area should be arranged with an air-lock and be maintained at overpressure relative to the external hazardous area.

5.2.6 Safety Functions of Gas supply system

GL VI-3-1, Section 5, 5.6.1
Each gas storage tank should be provided with a tank valve capable of being remote operated and is to be located as close to the tank outlet as possible.

GL VI-3-1, Section 5, 5.6.2
The main gas supply line to each engine or set of engines should be equipped with a manually operated stop valve and an automatically operated "master gas fuel valve" coupled in series or a combined manually and automatically operated valve. The valves should be situated in the part of the piping that is outside machinery space containing gas fuelled engines, and placed as near as possible to the installation for heating the gas, if fitted.

GL VI-3-1, Section 5, 5.6.3
Each gas consuming equipment should be provided with a set of "double block and bleed" valves, so that when automatic shutdown is initiated as given in Table below, this will cause the two gas fuel valves that are in series to close automatically and the ventilation valve to open automatically.

GL VI-3-1, Section 5, 5.6.3.1
The two block valves should be of the fail to-close type, while the ventilation valve should be fail-to-open.

40
GL VI-3-1, Section 5, 5.6.5
There should be one manually operated shutdown valve in the gas supply line to each engine upstream of the double block and bleed valves to assure safe isolation during maintenance on the engine.

5.3 Design Arrangement of Fuel Gas Supply System

5.3.1 LNG Tank

In this thesis, the LNG tank that will be installed is independent tank type C that having maximum working pressure of 5 bar. Based on GL rules, LNG tank can be located in enclosed deck and open deck. It’s not possible to install the LNG tank inside the laboratory or engine room because the laboratory or engine room, at the department of maritime studies in Warnemünde, doesn’t have enough space. Therefore, the LNG tank will be installed in the open deck or outside the laboratory. Figure 5.2 below shows the design arrangement and safety aspects for LNG tank that based on Germanischer Lloyd regulation and LNG tank manufacturer

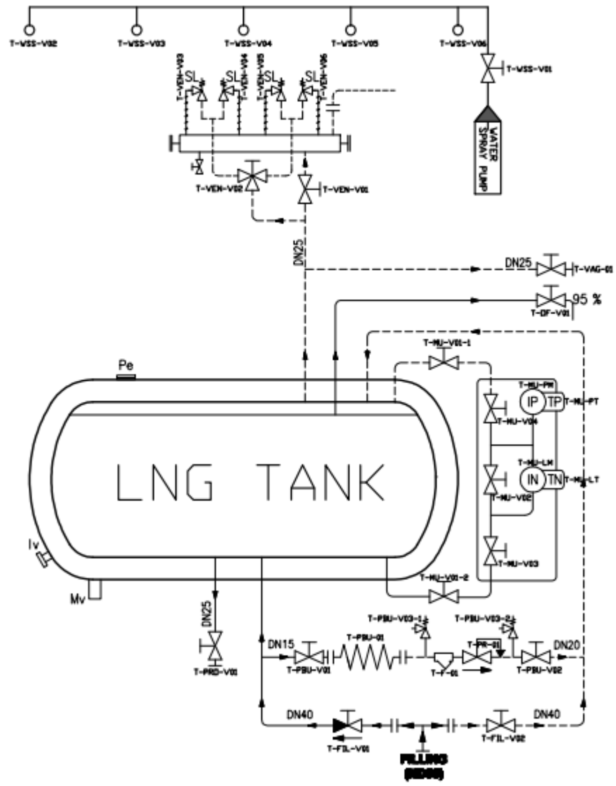


Figure 5.2 Design Arrangement of LNG Tank

Filling Connection

Every fuel gas system should be equipped with fill connection. The function of fill connection is to provide a connecting point to the re-fuelling station of LNG tank. Filling connection system also should be fitted with liquid phase non return valve. Its function is to prevent backflow through the fill line.

Venting System

According to GL VI-3-1, Section 2, 2.8.1.3, pressure relief valve should be fitted to the LNG tank. Single pressure relief valve will be installed because the tank volume not exceeding 20 m^3. According to GL I-1-6, Section 8, 8.2.1, when the volume cargo tank exceeding 20 m^3 is to be fitted at least two pressure relief valve.

The pressure relief valve is set at the maximum allowable working pressure (MAWP) of the tank. Based on GL VI-3-1, Section 2, 2.8.4.1, gas in liquid state may be stored with a maximum allowable working pressure of 10 bar. Therefore, its function is to vent product to atmosphere if the tank pressure exceeding of 10 bar.

In the venting system also equipped with line safety valve. Its function is to vent produce to atmosphere in the event of a malfunction of the pressure relief valve.

Pressure and Level Indicator for LNG Tank

According to GL VI-3-1, Section 5, 5.2.1 and 5.2.2, storage tank should be monitored with overfilling and pressure indicator. Where, storage tanks for liquid gas should not be filled to more than 95% of tank capacity and the maximum working pressure of 10 bar inside the storage tank. This number is based to the GL rules and LNG tank manufacturer. Therefore, a liquid level and pressure indicator should be fitted to prevent the LNG tank from becoming liquid full and over pressure.

Pressure Build-up Unit

In the pressure build-up process, cold LNG is drained from the tank bottom to the PBU. The flow is controlled by valve which located before the PBU on figure 5.2 above. According to the LNG tank manufacturer, the operation pressure is set 5 bar. When the pressure drops below 4.5 bar, the PBU is activated and it is de-activated when the tank pressure increases above 5 bar.

PBU cycle is driven by the thermosyphon effect: the flow through the PBU is not driven mechanically by a pump or similar, but by the heat transferred into the circuit in the PBU. The difference in density between LNG and NG gives a difference in the static pressure between the section from the liquid surface in the tank to the bottom of the PBU and the section from the bottom of the PBU through the PBU and back to the liquid surface. This enables the fluid to flow around in the circuit [13]. PBU converts liquid from the tank into gas and returns it to the tank, as a result of which the pressure in the tank can be increased.

5.3.2 Water Spray System

According to GL VI-3-1, Section 3, 3.3.2.1 and 3.3.2.2, when the storage tank located on open deck, a water spray system should be fitted for cooling and fire prevention. The system should arranged to cover all areas with an application rate of 10 l/min/m^2 for horizontal projected surfaces and 4 l/min/m^2 for vertical surfaces.

The capacity of the water spray pump should be sufficient to deliver the required amount of water as specified in GL VI-3-1, Section 3, 3.3.2.2. The capacity of water spray pump can be seen in chapter 4.2. The system shall be initiated automatically by the fire detection system. On detection of fire on any one storage tank, the water spray system on an adjacent storage tank shall operate by opening the control valve (spray valve).

Construction materials can be chosen by the client, based on the possible corrosive properties of the environment or of the used water. Control valves can be made of cast steel as well as from bronze, alubronze, stainless steel or duplex steel. Spray nozzles can be made of bronze or stainless steel. Piping shall be made of galvanised carbon steel [14].

5.3.3 Ventilation in double piping system

According to GL VI-3-1, Section 2, 2.7.1.1, gas piping system should be arranged with double wall piping. The space between the gas fuel piping and the wall of the outer pipe or duct should be equipped with mechanical under pressure ventilation. Ventilation air inlet is located at the engine and the outside of the tank connection space at the end of the double wall piping. Ventilation air is recommended to be taken from the outside of the engine room and safe area and equipped with a valve to regulate the air flow. The requirement of air exchange in double piping system is minimum 30 air changes per hour, these number is based of classification societies of Germanischer Lloyd.

Air flowing will be supplied to Gas Valve Unit room or to the enclosure of the gas valve unit. From the enclosure of the gas valve unit, the air will be ventilated by using ventilation fans and the air will be supplied to the safe area. According to GL rules, the ventilated air outlet should be placed in a position where no flammable gas and air mixture may be ignited and should be installed the gas detector to control any losses of the required ventilating capacity.

5.3.4 Gas Valve Unit

In gas valve unit (GVU) system, there are 6 pipes connections, such as: gas inlet connection, gas to engine connection, inert gas connection, gas venting connection, air venting connection, and instrument air connection. Gas is flowing to GVU system through gas inlet connection where the gas pressure is 5 – 10 bar(g). Gas will be filtered by a filter with maximum mesh width must be 0.005 mm [15]. The pressure loss at the filter is monitored by a differential pressure gauge. Before entering the engine, the gas pressure will be measured by pressure gauge, and gas also through double block and bleed valves.

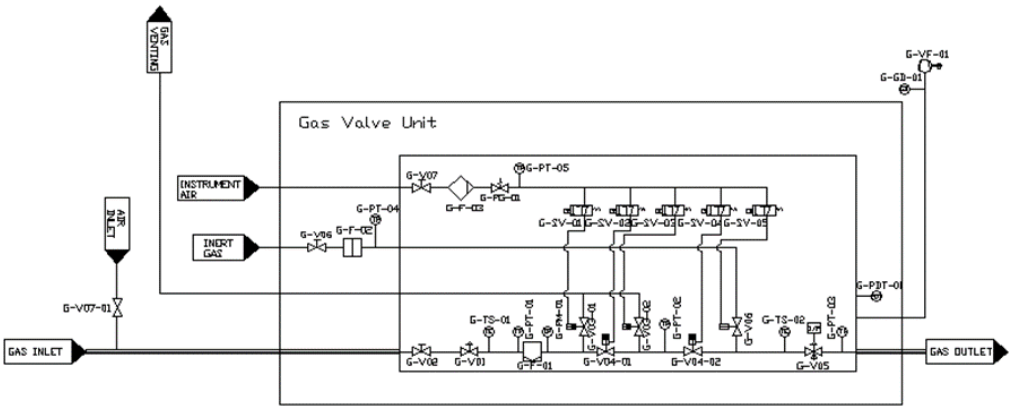


Figure 5.3 Design Arrangement of Gas Valve Unit

According to GL GL VI-3-1, Section 5, 5.6.3, fuel gas supply system should be provided with double block and bleed valves. Block valve will open when there is no failure occurred in the system. In the event of a failure in the gas supply system then the block valve will be closed and venting valve or bleed valve will automatically open. The function of the vent valve is to reduce the pressure of the gas in the pipeline and the gas can be ventilated outside the atmosphere. Connecting the engine or venting lines to the GVU LNGPac venting mast is not allowed, due to risk for backflow of gas into the engine room when LNGPac gas is vented. In gas valve unit system, there is a gas double wall system ventilation fan connection for supplying the air inside the GVU room to the safe area. According to GL rules, the maximum of ventilation fan capacity is 30 times per hour and the maximum length of the fuel gas pipe between GVU and gas inlet at engine should be kept as short as possible and not exceed 30 m.

5.3.5 Inert gas system

In gas valve unit system, there is a gas inert connection where before maintenance work is commenced on the engine and/or the GVU, it is required that any remaining natural gas is removed by substituting the natural gas with an inert gas, for example nitrogen. The GVU inerting process ensures that natural gas cannot leak to the surrounding areas, thus eliminating potential risks. If there is a failure of fuel gas supply system, block valve will be automatically closed and vent valve will be automatically opened. During this situation, the piping will be automatically purged with inert gas system, therefore on the dual fuel engine, an inert gas valve should be installed.

In case the nitrogen purging system fails, the gas pipe is once purged with charge air and a gas blocking is set. Thus an explosive atmosphere can only occur seldom and for short periods. Operation in gas mode is only possible if Nitrogen pressure is available and gas blocking alarm has been reset by operator.

CHAPTER VI
CONCLUSIONS

5.1 Conclusions

Based on the calculation result and design process of concept fuel gas supply system for laboratory, at the department of maritime studies in Warnemünde, there are some conclusions can be obtained as below:

1. The LNG and fuel gas consumption calculation of engine MAN 6L23/30 A is as table 5.1 below.

Table 5.1 LNG and Fuel Gas Consumption per Day

MAN 6L23/30 A		
Loads	**LNG Consumption (m^3/day)**	**Natural Gas Consumption (m^3/day)**
100%	2.58	1548
75%	2.02	1212
50%	1.50	900

Natural gas consumption is required to determine the specification of vaporizer, pipe diameter, and gas valve unit specification. According to natural gas facts (2004), the original volume of the LNG being converted into natural gas by a factor 600. LNG consumption calculation result is required to determine the capacity of LNG tank. In this LNG tank arrangement, the LNG tank should be able to serve the engine operation during one week (5 days). Based on the calculation result, the total LNG consumption per week is 12.908 m^3.

2. The selected components of fuel gas supply system can be seen in table 5.2 below.

Table 5.2 The Selected Components of Fuel Gas Supply System

Object	Value	Measurement Unit
LNG Tank		
Series	2200 H	
Model	LC16H22-P	
Volume	15.7	m^3
Stored Liquid Weight at 95%	6.9	Ton

Water Spray Pump		
Manufacturer	Evergush	
Type	XA50/26	
Q	38	m^3/h
Head	19.8	m
Speed	1450	RPM
Required Motor	4	kW
Vaporizer		
Vaporizer Type	Circulating Water	
Model	VWB-400	
LNG Flow Rate	400	kg/h
Water Flow Rate	5.1	m^3/h
LNG Pump		
Manufacturer	Vanzetti	
Type	VT-1 32 25	
Q	1.4 – 8.1	lpm
Power Installed	3 - 15	kW
Gas Valve Unit		
Manufacturer	Wartsila	
Type	GVU DN 100	

3. In this concept design of fuel gas supply system, there are three types of piping system that should be installed, such as pipe for liquid phase from LNG tank until the input of vaporizer, pipe for gas phase from output of vaporizer until engine manifold and pipe for water spray system. All the dimensions are accordance to DIN standard. The dimension of this pipe can be seen in table 5.3 below

Table 5.3 Pipe Diameter Dimension

Object	Value	Measurement Unit
Pipe Dimension of Gas Phase		
Inside Diameter	152.4	mm
Insulation Thickness	50	mm
Annular Gap	21	mm
Outside Diameter	304.8	mm
Pipe Dimension of Liquid Phase		
Inside Diameter	25.4	mm
Insulation Thickness	20	mm

Annular Gap	17	mm
Outside Diameter	101.6	mm
Pipe Dimension of Water Spray System		
Inside Diameter	133.1	mm
Wall Thickness	5.4	mm
Outside Diameter	138.5	mm
Nominal Diameter	DN 125	

4. The drawings result and safety aspect of fuel gas supply system can be found at:

a. Attachment 1 : Concept Design of Fuel Gas Supply System
b. Attachment 2 : LNG Tank Design and Safety Aspect
c. Attachment 3 : Side View Design of Component Installation
d. Attachment 4 : Top View Design of Component Installation

5. The location of each components should be considered based on the regulation to achieve the optimum design arrangement. According to GL rules, LNG tank can be located in the opened space and closed space. In this design arrangement, the LNG tank located in the open space because the laboratory doesn’t have enough space. The gas valve unit is enclosed design type because it can be located inside the engine room and it’s not require installation in an explosion-proof gas valve unit room. All the equipment of gas valve unit type enclosed design is mounted inside a gas tight casing and it can minimise the installation costs. LNG pump and vaporizer are located in the open space to avoid a gas explosion when operating failure occurred on LNG pump and vaporizer.

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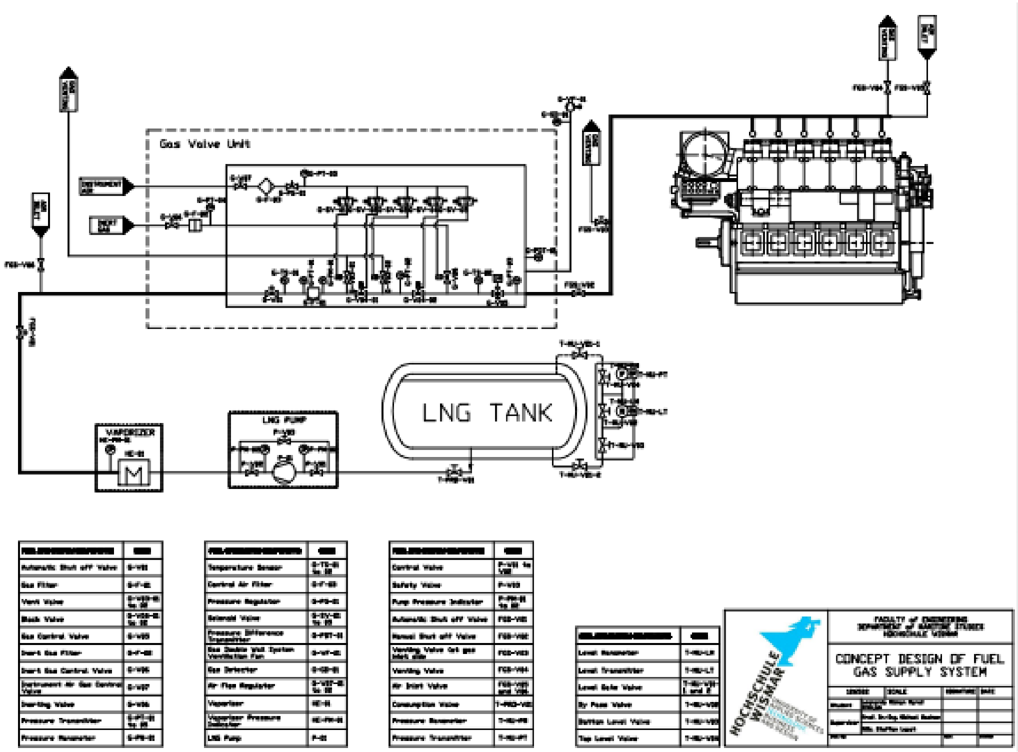
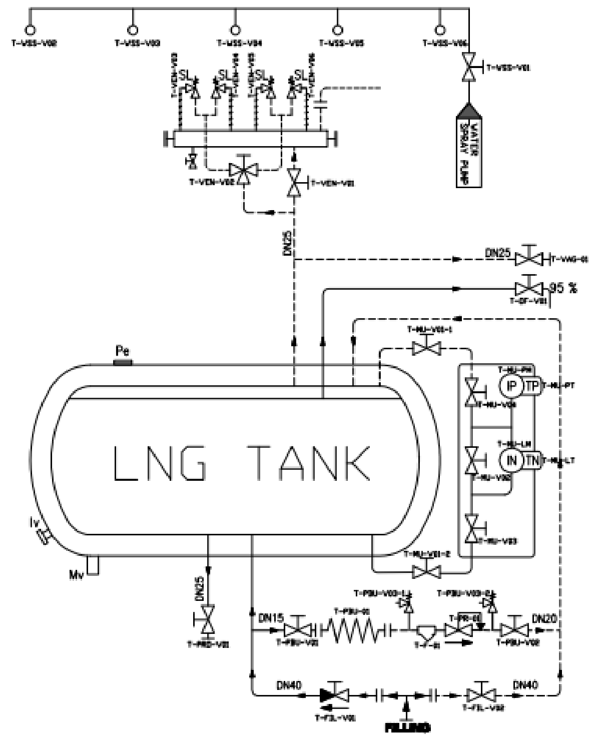
Attachment 1
Concept Design of Fuel Gas Supply System

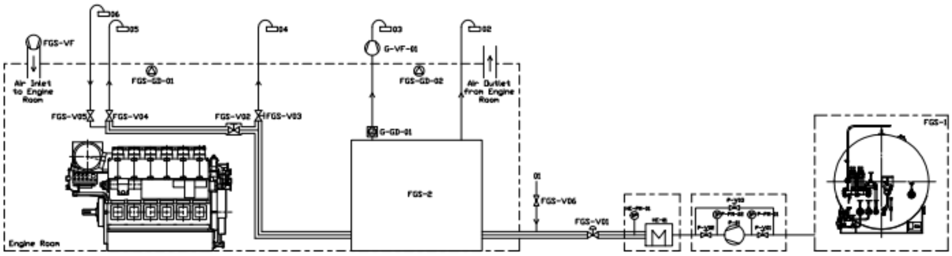


Attachment 2
LNG Tank Design and Safety Aspect



	Consumption Valve	T-PRD-V01	1
	Gas Phase Filling Valve	T-FIL-V02	1
	Liquid Phase Filling Valve	T-FIL-V01	1
	Overflow Valve	T-OF-V01	1
	Pressure Build-up Unit	T-PBU-01	1
	Input Valve PBU	T-PBU-V01	1
	Output Valve PBU	T-PBU-V02	1
	Filter	T-F-01	1
	Pressure Regulator	T-PR-01	1
	Safety Valve	T-PBU-V03-1	2
	Pressure Manometer	T-MU-PM	1
	Pressure Transmitter	T-MU-PT	1
	Auxiliary Valve-Gas Phase	T-VAG-01	1
	Level Manometer	T-MU-LM	1
	Level Transmitter	T-MU-LT	1
	Level Gate Valve	T-MU-V01	2
	By Pass Valve	T-MU-V02	1
	Bottom Level Valve	T-MU-V03	1
	Top Level Valve	T-MU-V04	1
	Pressure Relief Valve	T-VEN-V01	1
	3-Way Valve (Safety)	T-VEN-V02	1
	Safety Valve	T-VEN-V03	4
	Control Valve	T-WSS-V01	1
	Nozzle	T-WSS-V02	5
PE	Casing Safety Device		
TV	Vacuum Connection		
MV	Vacuum Gauge Device		

Attachment 3
Side View Design of Component Installation



CODE	DESCRIPTION
FGS-1	LNG Tank
P-01	LNG Pump
P-V01	Control Valve
P-V02	Control Valve
P-V03	Safety Valve
P-PM-01	Pump Pressure Indicator
P-PM-02	Pump Pressure Indicator
HE-01	Vaporizer
HE-PM-01	Vaporizer Pressure Indicator
FGS-V01	Automatic Shut off Valve
FGS-V02	Manual Shut off Valve
FGS-V03	Venting Valve (at gas inlet side)
FGS-V04	Venting Valve
FGS-V05	Air Inlet Valve
FGS-V06	Air Inlet Valve

CODE	DESCRIPTION
FGS-VF	Ventilation Fan (engine room)
FGS-2	Gas Valve Unit
G-GD-01	Gas Detector (GVU)
G-VF-01	Ventilation Fan (GVU)
FGS-GD-01	Gas Detector (engine room)
FGS-GD-02	Gas Detector (engine room)

CODE	DESCRIPTION
01	Air Inlet for GVU
02	Venting Pipe from GVU
03	Ventilation Air Pipe for GVU
04	Venting Pipe (at gas inlet side)
05	Venting Pipe
06	Air Inlet Annular Space

SYMBOL	DESCRIPTION
	Double Wall Pipes Normal Operation Inner Pipe - Gas Annular Space - Air Inerting Procedure Inner Pipe - Nitrogen Annular Space - Air
	Vent Pipes
	Air Pipes

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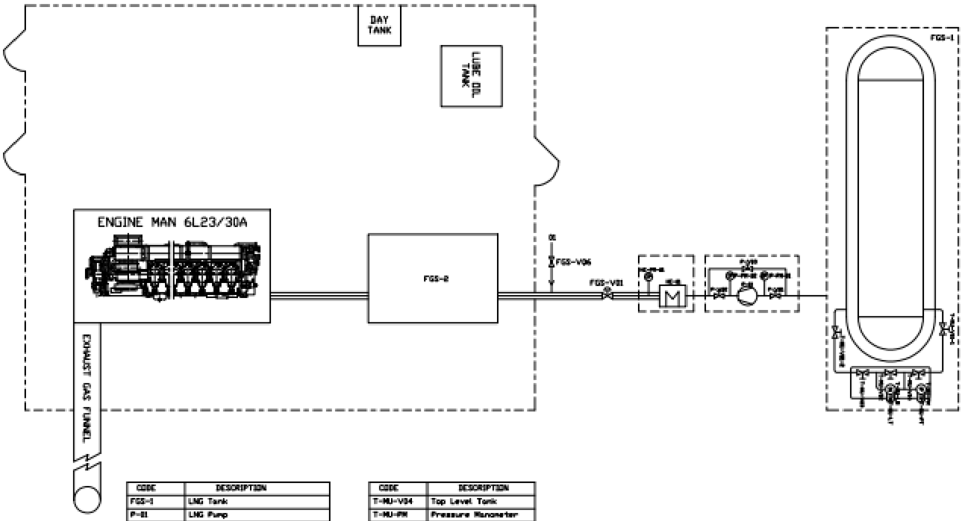
SIDE VIEW OF COMPONENT INSTALLATION

	SCALE	SIGNATURE	DATE
Student			
Supervisor	Prof. Dr-Ing. Michael Rachow		

Attachment 4
Top View Design of Component Installation



CODE	DESCRIPTION
FGS-1	LNG Tank
P-01	LNG Pump
P-V01	Control Valve
P-V02	Control Valve
P-V03	Safety Valve
P-PM-01	Pump Pressure Indicator
P-PM-02	Pump Pressure Indicator
HE-01	Vaporizer
HE-PM-01	Vaporizer Pressure Indicator
FGS-V01	Automatic Shut off Valve
FGS-V06	Air Inlet Valve
T-MU-V01-1	Level Gate Valve
T-MU-V01-2	Level Gate Valve
T-MU-V02	By Pass Valve
T-MU-V03	Bottom Level Valve

CODE	DESCRIPTION
T-MU-V04	Top Level Tank
T-MU-PM	Pressure Manometer
T-MU-PT	Presure Transmitter
T-MU-LM	Level Manometer
T-MU-LT	Level Transmitter
01	Air Inlet for GVU

SYMBOL	DESCRIPTION
	Double Wall Pipes Normal Operation Inner Pipe - Gas Annular Space - Air Inerting Procedure Inner Pipe - Nitrogen Annular Space - Air
	Vent Pipes

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TOP VIEW OF COMPONENT INSTALLATION

Attachment 5 LNG Tank Type 2200 H Technical Data

lapesa LNG

STATIC TANKS FOR **LNG** STORAGE

HORIZONTAL CRYOGENIC TANKS FOR LIQUEFIED NATURAL GAS

2200 H SERIES

2200 H SERIES

Designation example "LC6H22-P05": LC: lapesa cryogenic tank, 6: vnominal volume 6 m^3, H: horizontal installation, 22: diameter 2,200 mm, P05: maximum working pressure 5 bar

MAIN FEATURES		LC5H22-P..*	LC6H22-P..*	LC11H22-P..*	LC16H22-P..*	LC20H22-P..*
NOMINAL VOLUME	m^3	5,0	6,0	11,0	16,0	20,0
NET VOLUME	m^3	4,9	6,2	10,9	15,7	19,9
MAXIMUM WORKING PRESSURE	bar	*(P) : 05, 10, 13, 16, 22, 28, 35				
DESIGN TEMPERATURE	°C	-196	-196	-196	-196	-196
STANDARDS		EC marking: European directive 2014/68/EU, (optional) ASME stamp: ASME VIII, div.1				
INNER TANK	material	austenitic stainless steel				
OUTER TANK	material	carbon steel				
INSULATION		Perlite insulating material, vacuum < 5 * 10 $^{-2}$				
INTERNAL FINISH		Particle free				
EXTERNAL FINISH		SA 2 1/2 blasting/ 60 micron polyamide epoxy primer / 60 micron white polyurethane finish				

TECHNICAL DETAILS		LC5H22-P..*	LC6H22-P..*	LC11H22-P..*	LC16H22-P..*	LC20H22-P..*
LNG USEFUL CAPACITY (95%, 1 bar)	mt	2,2	2,7	4,8	6,9	8,7
PRESSURE BUILD UP UNIT (PBU) CAPACITY (for NG consumption at 3,5 bar)[1]	Nm^3/h	370	370	370	370	370

(1) Please consult us for other flow and/or pressure requirements.

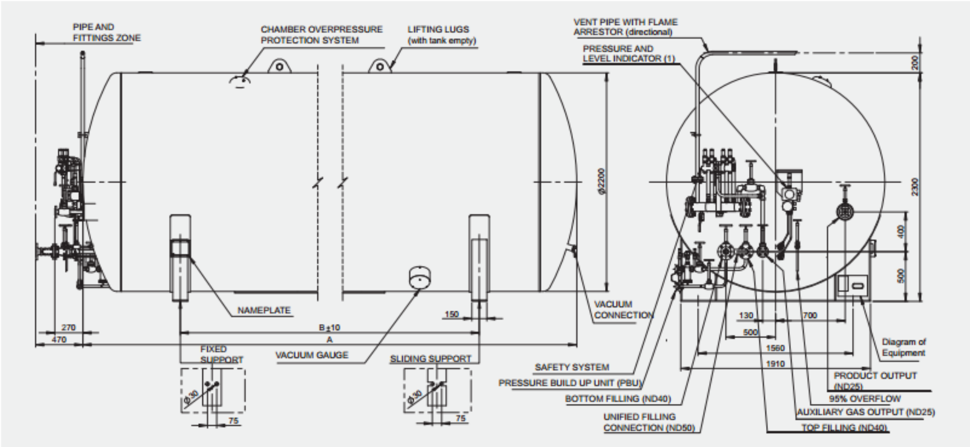
EQUIPMENT INCLUDED

- Vent pipe with flame arrester: directional.
- Vacuum gauge sensor.
- Standard filling connection: ND50.
- Electronic level indicator (with pressure and liquid level transmitter): SAMSON.
- Regulator and economiser valves: CASH, SAMSON, HEROSE
- Pressure build up unit (PBU).
- Safety valve block: HEROSE, CAEN.
- General valves: HEROSE, CAEN, BESTOBELL.

OPTIONAL EQUIPMENT

- External economiser kit with pressure regulator, filter and shut-off valve.
- Internal economiser: ND20.
- Pressure build up unit: PBU/ other capacities.
- Level indicator: mechanical.
- Fittings/valves: other makes.
- Valves pneumatically driven.
- Double Filling valve
- High point: double.

STATIC TANKS FOR **LNG** STORAGE



DETAILS FOR HANDLING AND TRANSPORT			LC5H22-P..*	LC6H22-P..*	LC11H22-P..*	LC16H22-P..*	LC20H22-P..*
Approx. tare when empty (tank with full equipment)	mt	P05	2,9	3,3	4,6	5,9	7,1
		P10	2,9	3,3	4,6	5,9	7,1
		P13	3,0	3,4	4,8	6,1	7,5
		P16	3,1	3,5	5,0	6,4	7,8
		P22	3,5	3,9	5,6	7,2	8,7
		P28	3,7	4,2	6,1	7,8	9,5
		P35	4,0	4,5	6,5	8,4	10,3
L: total length including valves	mm		3.525	4.065	6.065	8.065	9.845
D: total width	mm		2.200	2.200	2.200	2.200	2.200
H: total height including vent pipe	mm		2.450	2.450	2.450	2.450	2.450
P: distance between supports	mm		1.000	1.500	3.500	5.500	7.300

Attachment 6 LNG Pump Vanzetti Technical Data

VANZETTI®
CRYOGENIC TECHNOLOGY

CRYOGENIC RECIPROCATING PUMPS

VT-1 L SERIES

for ***LIQUEFIED NATURAL GAS (LNG)***

Technical features

- Compatible with Cold Converter and Thermosyphon storage tanks
- Easy installation due to the 360° rotating inlet and outlet
- High efficiency
- Low operating noise
- Quick maintenance thanks to the integrated cartridge seal system

Applications

- L-CNG refueling stations for cars/trucks/buses, cylinders and buffer filling

Crankdrive lubrication

- **TW 6,5** - Oil lubrication

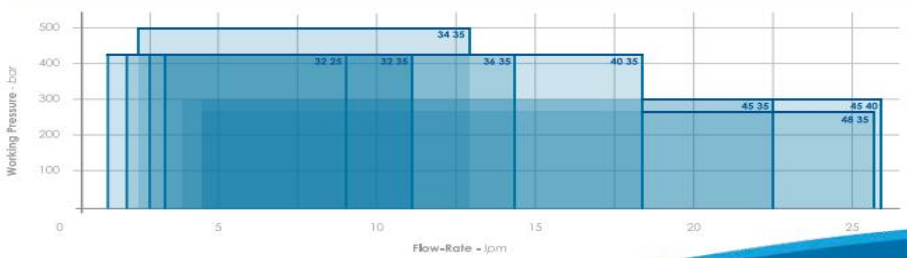
Transferred fluids

- LNG

PERFORMANCE

VT-1 TW6.5	Piston		Flow-rate				Maximum allowable suction pressure (MASP)		Maximum allowable working pressure (MAWP)		Power installed
	Bore	Stroke	Min 80 rpm		Max 450 rpm						Referred to MAWP
Series pump	mm	mm	lpm	gpm	lpm	gpm	bar	psi	bar	psi	kW
VT-1 32 25	32	25	1,4	0,4	8,1	2,1	20	290	420	6090	3 - 15
VT-1 32 35	32	35	2,0	0,5	11,4	3,0	20	290	420	6090	4 - 22
VT-1 34 35	34	35	2,3	0,6	12,9	3,4	20	290	500	7250	5,5 - 30
VT-1 36 35	36	35	2,6	0,7	14,4	3,8	20	290	420	6090	5,5 - 30
VT-1 40 35	40	35	3,2	0,8	17,8	4,7	20	290	420	6090	5,5 - 30
VT-1 45 35	45	35	4,0	1,1	22,5	6,0	20	290	300	4350	5,5 - 30
VT-1 48 35	48	35	4,6	1,2	25,6	6,8	20	290	260	3770	5,5 - 30
VT-1 45 40	45	40	4,6	1,2	25,8	6,8	20	290	300	3770	5,5 - 37

NPSH required: 1,5 - 1,7 m H_2O



www.vanzettiengineering.com

Standard Scope of Supply

- Hot dipped galvanized steel skid
- Cryogenic pump
- Electric motor
- Transmission by belt and pulley
- Pulsation damper

Standard Accessorise

- Suction flexible hose
- Return flexible hose
- Low pressure safety valve
- High pressue safety valve
- High pressure pneumatic valve for venting
- Check valve
- Pressure gauge
- Pressure switch
- Temperature sensor for cool down
- Temperature sensor for cavitation
- Temperature sensor for leaks detection

Optional

- Flushing system with nitrogen gas
- Electrical control panel
- 2 speed electric motor
- Motor suitable for VFD
- Customized electrical control panel available on demand
- Completely automated systems available on demand

Average SKID weight:
420 kg

Package overall dimensions
195 x 86 x 115 cm

Test and controls

- Dimensional control of each mechanical component before assembly
- Running test of each pump with LIN before delivery

Standards

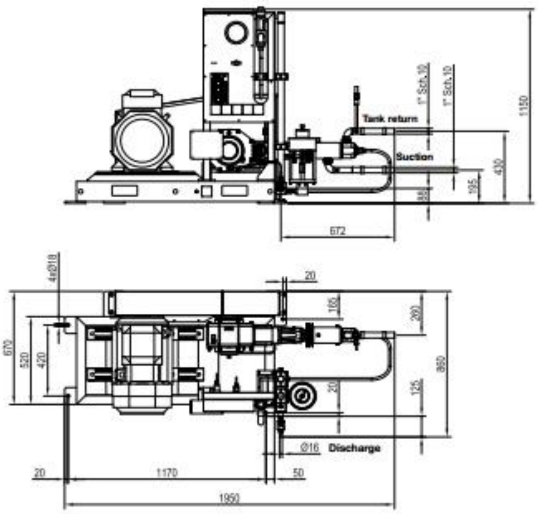
Designed according to:

- European Directive 2006/42/CE Machinery
- European Directive PED 97/23/CE
- European Directive 94/9/CE ATEX*
- EIGA/IGC/CGA guidelines

*VT-1 Skids are ATEX certified for "zone 1".

II 2G ck IIB T4

GENERAL DIMENSIONS

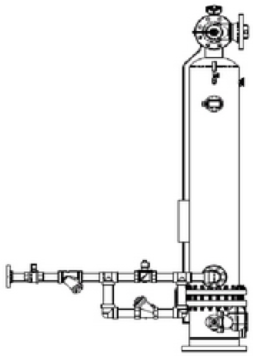


Cold End Particular
The innovative seal cartridge allows a very easy maintenance

ISO 9001
Certified quality management system

Vanzetti Engineering s.r.l.
Via dei Mestieri, 3 - 12030 Cavallerleone (CN) ITALY
Tel. (+39) 0172 915811 - Fax (+39) 0172 915822
www.vanzettiengineering.com

Attachment 7 Circulating Water Vaporizer Technical Data



- Capacities from 200 gph to 3000++ gph
- For Propane, Butane, and other LPG
- Shell-and-Tube Heat Exchanger
- ASME "U"-stamped
- Ex-proof Class I, Div 1, Group D
- Small Footprint, High Efficiency
- PLC Controls with First-Out Monitor
- Local Start/Stop Station
- Dual Liquid Carryover Protection with "Smart" Liquid Carryover Function and Ultrasonic Liquid Level Control
- UL stamped external Relief Valve
- All-welded Liquid Inlet Assembly
- Flanged Steam Inlet with Steam Temperature Regulator and
  Steam Back Check
- Option: Walk-in Control Room
- Option: Remote Monitoring and Operation (Modem, Ethernet, Wireless)
- Option: Integration with LPG/Air Mixers for Standby Systems and
  Peak Shaving Systems
- Option: Chinese Pressure Vessel Approval
- Option: 6-inch color LCD Display with Touch Screen Operator Interface, alarm history, and local trend recording.

General Description

Alternate Energy Systems offers a complete line of circulating-hot-water vaporizers in capacities from 200 gallons per hour to 3000 gallons per hour.The heat exchanger tube bundle is of multi-pass design to transfer the maximum heat to the liquid. The tube bundle and all propane piping conform to Section VIII, Division I of the latest edition of the ASME Boiler and Pressure Vessel Code. The pressure vessel carries the ASME "U" stamp and is National Board registered.

VWB vaporizers in standard configuration include temperature regulator; dual liquid carryover protection through ultrasonic liquid level transmitter in the pressure vessel, and "smart" liquid carryover protection with Rosemount pressure transmitter and temperature transmitter in the vapor outlet; and liquid inlet valve. Temperature gauges in water inlet and outlet, and in pressure vessel shell and vapor outlet, are standard.

Vaporizer design, wiring, controls, and electrical components and their installation comply with the latest editions of NFPA #58 and NFPA #70.

All safety devices of the vaporizer, including the dual liquid carryover protection, are monitored by a programmable logic controller (Allen-Bradley MicroLogix-1100 or Siemens S7-1200), which is connected to an operator interface with high-resolution LCD display and touch screen. The operator interface provides start/stop control for the vaporizer; it displays the system status, and any failure conditions that may occur, in plain English (with date/time stamp). The electrical enclosure for the PLC and the operator interface are to be installed in non-classified location.

A small explosion-proof enclosure at the vaporizer provides local start/stop and alarm reset functions.

NOTE:
The hot-water consumption of VWB Vaporizers is proportional to the actual vaporization rate. The consumption rates given in the table below are based on 185°F (85 °C) water temperature and 40°F (22°C) inlet/outlet temperature drop.

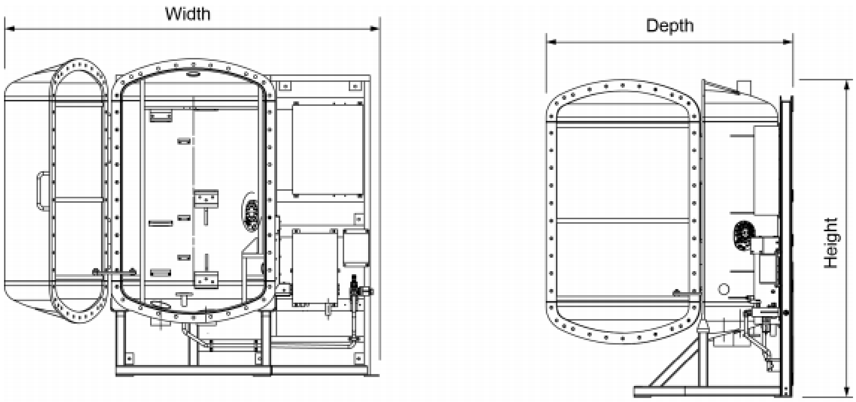
Model Number	Nominal Capacity (Propane & LPG up to 30/70 Propane/Butane)				Water Flow (185 °F / 85 °C)		Shipping Weight	Dimensions L x W x H inches / m
	gph	MMBTU/h	kg/h	MMkcal/h	gpm	l/min	lb / kg	
VWB- 400	200	18.4	400	46	23	85	600 / 275	18" x 25" x 88" 0.45m x 0.65m x 2.24m
VWB- 800	400	37	800	93	46	170	770 / 350	
VWB-1200	600	55	1200	139	69	255	1060 / 480	
VWB-1600	800	74	1600	185	92	340	1150 / 520	
VWB-2000	1000	92	2000	232	115	425	1570 / 715	27" x 37" x 94" 0.6m x 0.95m x 2.40m
VWB-3000	1500	138	3000	348	173	638	1880 / 855	
VWB-4000	2000	184	4000	464	230	850	2350 / 1065	34" x 43" x 103" 0.9m x 1.10m x 2.65m
VWB-5000	2500	230	5000	580	288	1063	2520 / 1145	
VWB-6000	3000	276	6000	696	345	1275	2910 / 1320	

Common Specifications	
Design Temperature	650 °F / 343 °C
Design Pressure	250 psi / 17 bar
Test Pressure	375 psi / 26 bar
Relief Valve Setpoint	250 psi / 17 bar
Electrical	AC 110 V 60 Hz, Single Phase, 5 A / AC 220/240 V 50 Hz, Single Phase, 5A

Source: *http://www.nebimak.com/circulating-hot-water-vaporizers.html*

Attachment 8 Gas Valve Unit Technical Data

Pipe connections		Size GVU DN80	Size GVU DN100	Pressure class	Standard
A1	Gas inlet [5-10 bar(g)]	DN80 / DN125	DN100 / DN150	PN16	ISO 7005-1
B1	Gas outlet	DN80 / DN125	DN100 / DN150	PN16	ISO 7005-1
B2	Inert gas [max 15 bar(g)]	G1 ' '	G1 ' '	PN16	DIN 2353
D1	Gas venting	OD28	DN32		DIN 2353
D2	Air venting	DN80	DN100	PN16	
X1	Instrument air [6-8 bar(g)]	G1/2 ' '	G1/2 ' '		DIN 2353



	DN 80	DN 100
Height	2335 mm	2710 mm
Width	2710 mm	3200 mm
Depth	1730 mm	2200 mm

Source: Wartsila 50 DF Product Guide

Attachment 9 Water Spray Pump Technical Data

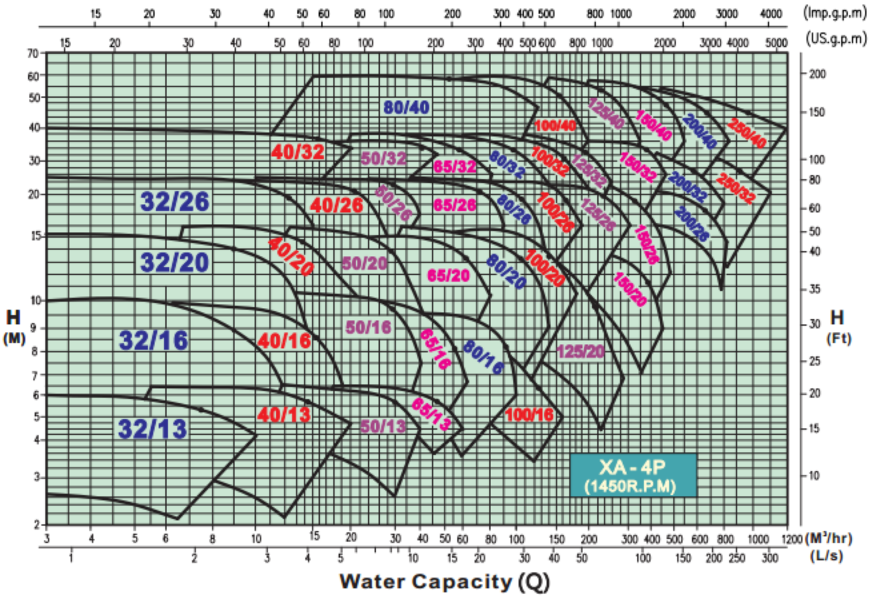
Applications

- Air conditioning systems(cooling tower)
- Broad range of industrial applications
- Temporary water supply booster systems
- Open loop or close loop circulation systems
- Water supply to multi-storey buildings or households. Fire fighting systems.

Product features

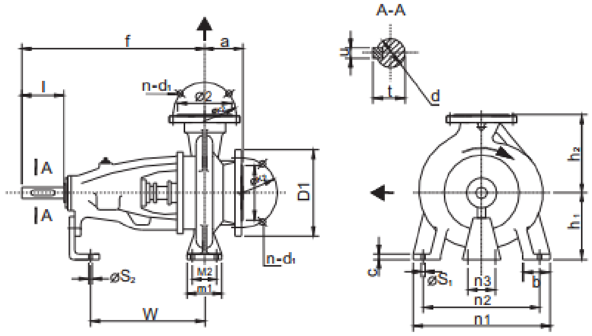
1. Back-pull out design which allows the pump bearing frame and impeller to be backed out of the volute without disturbing the pump piping connections. Also lower cost for maintenance and repair.
2. Specially designed wear-resisting mechanical seal--general use of life time exceeds 100,000 hours. Minimizes leakage and maximizes bearing life even operate under high pressure.
3. It requires only 5 kinds of overhangs, 6 kinds of shafts and 4 kinds of bearings for entire series of 42 models. It will effectively minimize accessory inventory and enhance pump components interchangeability.
4. Good suction performance--Bigger suction structure which lowers suction flow rate enable the pumps have better suction performance. Increases reliability and maximizes impeller and casing life.
5. Complies with international standard EN733(DIN24255) for interchangeability of components between all individual pump sizes.
6. Adopting molded impeller, copper o-ring, stainless steel shaft and bearing for high quality products.
7. Adopting TATUNG motor which conforms to insulation class F and protection IP54.

Performance Range:



Performance Tables（4P）

Type	Outer dia. Of Impeller (mm)	Capacity		Head (m)	Speed (r/min)	Power (kW)		Required Motor	Efficiency (%)	NPSHR (m)	Dia of Pump		Dia of Taper Pipe (mm)		Pump Weight (kg)
		(m^3/h)	(L/s)			Shaft Power	Motor Power				Inlet	Outlet	Inlet	Outlet	
XA50/26	Ø264	20	5.55	25	1450	2.62	3	4kW	52	2.3	65	50	80	65	101
		32	8.89	22.5		3.27	4		60	2.4					
		38	10.6	19.8		3.63	4		56.6	3					



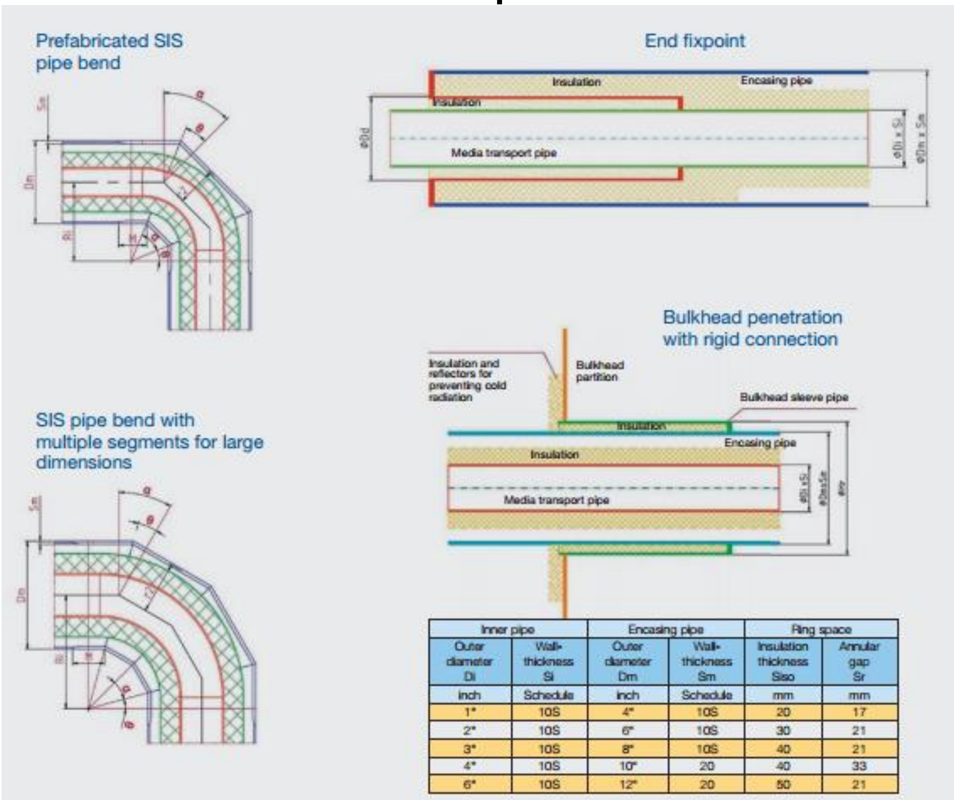
Flange Connecting Dimensions

φ1,φ2	32	40	50	65	80	100	125	150	200	250	300	350
$\varphi K_1,\varphi K_2$	100	110	125	145	160	180	210	240	295	355	410	470
D1,D2	140	150	165	185	200	220	250	285	340	405	460	520
n-d1	4-φ18	4-φ18	4-φ18	4-φ18	8-φ18	8-φ18	8-φ18	8-φ22	12-φ22	12-φ26	12-φ26	16-φ26

Overall and Mounting Dimensions Table(mm):

Type	Shaft Diameter	Pump Dimensions						Pump Foot Dimensions										Shaft End			
		φ1	φ2	a	f	h_1	h_2	b	c	m_1	m_2	n_1	n_2	n_3	φS_1	φS_2	w	d	l	t	u
XA3213	25	50	32	80	360	112	140	50	14	100	70	190	140	100	14	14	267	24	50	27	8
XA3216	25	50	32	80	360	132	160	50	14	100	70	240	190	100	14	14	267	24	50	27	8
XA3220	25	50	32	80	360	160	180	50	14	100	70	240	190	110	14	14	267	24	50	27	8
XA3226	25	50	32	100	360	180	225	65	14	125	95	320	250	110	14	14	267	24	50	27	8
XA4013	25	65	40	80	360	112	140	50	14	100	70	210	160	100	14	14	267	24	50	27	8
XA4016	25	65	40	80	360	132	160	50	14	100	70	240	190	100	14	14	267	24	50	27	8
XA4020	25	65	40	100	360	160	180	50	14	100	70	265	212	110	14	14	267	24	50	27	8
XA4026	25	65	40	100	360	180	225	65	14	125	95	320	250	110	14	14	267	24	50	27	8
XA4026G	35A	65	40	100	454	180	225	65	14	125	95	320	250	110	14	14	327	32	80	35	10
XA4032	35	65	40	125	470	200	225	65	14	125	95	345	280	110	14	14	342	32	80	35	10
XA4032G	45A	65	40	125	519	200	225	65	14	125	95	345	280	110	14	14	362	42	110	45	12
XA5013	25	65	50	100	360	132	160	50	14	100	70	240	190	100	14	14	267	24	50	27	8
XA5016	25	65	50	100	360	160	180	50	14	100	70	265	212	110	14	14	267	24	50	27	8
XA5020	25	65	50	100	360	160	200	50	14	100	70	265	212	110	14	14	267	24	50	27	8
XA5020G	35A	65	50	100	455	160	200	50	14	100	70	265	212	110	14	14	327	32	80	35	10
XA5026	25	65	50	100	360	180	225	65	14	125	95	320	250	110	14	14	267	24	50	27	8
XA5026G	35A	65	50	100	454	180	225	65	14	125	95	320	250	110	14	14	327	32	80	35	10
XA5032	35	65	50	125	470	225	280	65	16	125	95	345	280	110	14	14	342	32	80	35	10
XA5032G	45A	65	50	125	523.5	225	280	65	14	125	95	345	280	110	14	14	364	42	110	45	12

Attachment 10 LNG and Fuel Gas Pipe Technical Data



Inner pipe		Encasing pipe		Ring space	
Outer diameter Di	Wall-thickness Si	Outer diameter Dm	Wall-thickness Sm	Insulation thickness Siso	Annular gap Sr
inch	Schedule	inch	Schedule	mm	mm
1"	10S	4"	10S	20	17
2"	10S	6"	10S	30	21
3"	10S	8"	10S	40	21
4"	10S	10"	20	40	33
6"	10S	12"	20	50	21

Source: Technical Data FW LNG Pipe (FW-Fernwarme-Technik GmbH, Celle, Germany)

AUTHOR BIOGRAPHY

Author was born in Batam, 23rd January 1995 as the first child in his family. The author accomplished his formal education in SDS TUNAS BARU Batam, SMP TUNAS BARU Batam, and SMAN 5 Batam. The author continue his study in Double Degree Program of Marine Engineering Department, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember (ITS) Surabaya with Hochschule Wismar Germany. The author has done his On Job Training in Bandar Abadi Shipyard Batam, Pertamina Shipping Jakarta and Lloyd Register Batam. In the last year at Marine Engineering Department, the author took the Marine Power Plant (MPP) Laboratory for his concern to complete the bachelor thesis.